US009511598B2

(12) **United States Patent**
Wells, Jr. et al.

(10) **Patent No.: US 9,511,598 B2**
(45) **Date of Patent: *Dec. 6, 2016**

(54) **RECIRCULATION OF INK**

(71) Applicant: **FUJIFILM Dimatix, Inc.**, Lebanon, NH (US)

(72) Inventors: **Robert L Wells, Jr.**, Thetford Center, VT (US); **Bailey Smith**, Bow, NH (US); **Marlene McDonald**, Norwich, VT (US); **William R. Letendre**, Etna, NH (US); **Matthew Aubrey**, White River Junction, VT (US); **John Kelly**, Lebanon, NH (US); **Darrell Herrick**, White River Junction, VT (US); **Robert A. Hasenbein**, Scottsdale, AZ (US)

(73) Assignee: **FUJIFILM Dimatix, Inc.**, Lebanon, NH (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/867,766**

(22) Filed: **Sep. 28, 2015**

(65) **Prior Publication Data**

US 2016/0052292 A1 Feb. 25, 2016

Related U.S. Application Data

(63) Continuation of application No. 14/268,491, filed on May 2, 2014, now Pat. No. 9,144,993, which is a

(Continued)

(51) **Int. Cl.**

B41J 2/18	(2006.01)
B41J 27/10	(2006.01)
B41J 2/14	(2006.01)

(52) **U.S. Cl.**

CPC ***B41J 2/18*** (2013.01); ***B41J 2/14274*** (2013.01); ***B41J 27/10*** (2013.01); *B41J 2002/14362* (2013.01); *B41J 2002/14491* (2013.01)

(58) **Field of Classification Search**

CPC ... B41J 2/18; B41J 2002/1853; B41J 2202/12; B41J 2/175; B41J 2/17503; B41J 2/17563; B41J 2/17566

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,404,566 A	9/1983	Clark et al.
4,680,696 A	7/1987	Ebinuma et al.

(Continued)

FOREIGN PATENT DOCUMENTS

JP	2009-323431	12/1997
JP	2001-205810	7/2001
WO	WO 2011/146069	11/2011

OTHER PUBLICATIONS

International Search Report & Written Opinion, PCT/US2013/029213, mailed Jun. 24, 2013, 10 pages.

(Continued)

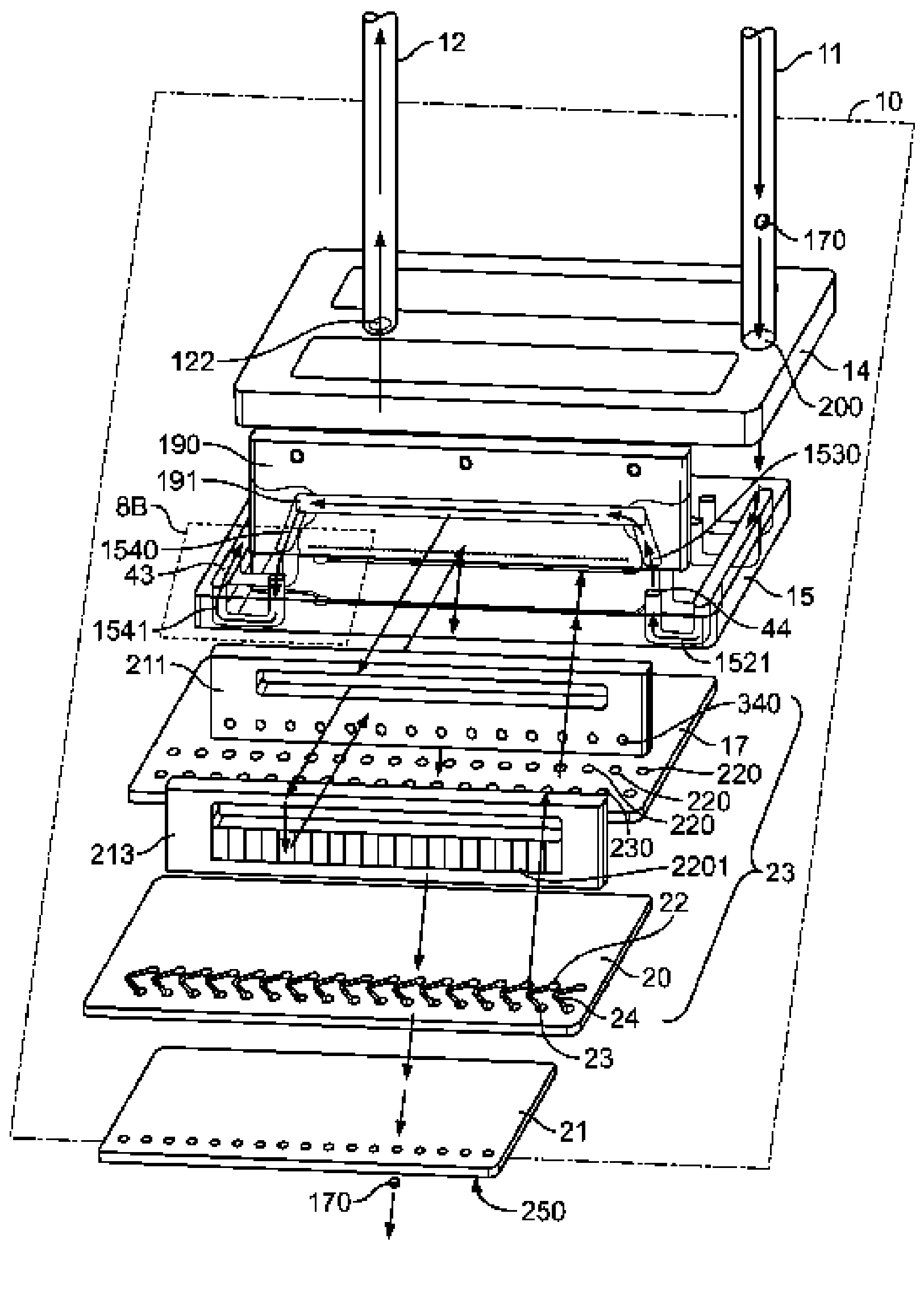
Primary Examiner — Kristal Feggins

(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57) **ABSTRACT**

An apparatus includes an inkjet assembly having inkjet nozzles through each of which ink flows at a nominal flow rate as it is ejected from the nozzle onto a substrate. Ink is held under a nominal negative pressure associated with a characteristic of a meniscus of the ink in the nozzle when ejection of ink from the nozzle is not occurring. The apparatus includes recirculation flow paths, each flow path having a nozzle end at which it opens into one of the nozzles and another location spaced from the nozzle end that is to be subjected to a recirculation pressure lower than the nominal negative pressure so that ink is recirculated from the nozzle

(Continued)



through the flow path at a recirculation flow rate. Each recirculation flow path has a fluidic resistance between the nozzle end and the other location such that a recirculation pressure at the nozzle end of the flow path that results from the recirculation pressure applied at the other location of the flow path is small enough so that any reduction in flow rate below the nominal flow rate when ink is being ejected is less than a threshold, or a change in the nominal negative pressure when ink is not being ejected is less than a threshold, or both.

18 Claims, 17 Drawing Sheets

Related U.S. Application Data

continuation of application No. 13/786,360, filed on Mar. 5, 2013, now Pat. No. 8,752,946.

(60) Provisional application No. 61/606,880, filed on Mar. 5, 2012, provisional application No. 61/606,709, filed on Mar. 5, 2012.

(58) **Field of Classification Search**
USPC 347/84, 85, 89, 74
See application file for complete search history.

(56) References Cited

U.S. PATENT DOCUMENTS

4,891,654	A	1/1990	Hoisington et al.	
5,701,149	A	12/1997	Pagnon et al.	
5,818,485	A	10/1998	Rezanka	
6,244,694	B1	6/2001	Weber et al.	
6,371,607	B2	4/2002	Wouters et al.	
6,517,197	B2	2/2003	Hawkins et al.	
8,091,988	B2	1/2012	McDonald	
8,491,100	B2	7/2013	Moynihan	
8,752,946	B2	6/2014	Wells, Jr. et al.	
9,144,993	B2 *	9/2015	Wells, Jr.	B41J 2/18 347/89
2008/0049063	A1	2/2008	Nakamura et al.	
2009/0079801	A1	3/2009	Moynihan et al.	
2009/0290000	A1	11/2009	McDonald	
2011/0148988	A1	6/2011	Hoisington et al.	
2012/0050427	A1	3/2012	Rike et al.	

OTHER PUBLICATIONS

International Search Report & Written Opinion, PCT/US2013/029202, mailed Jun. 26, 2013, 17 pages.

* cited by examiner

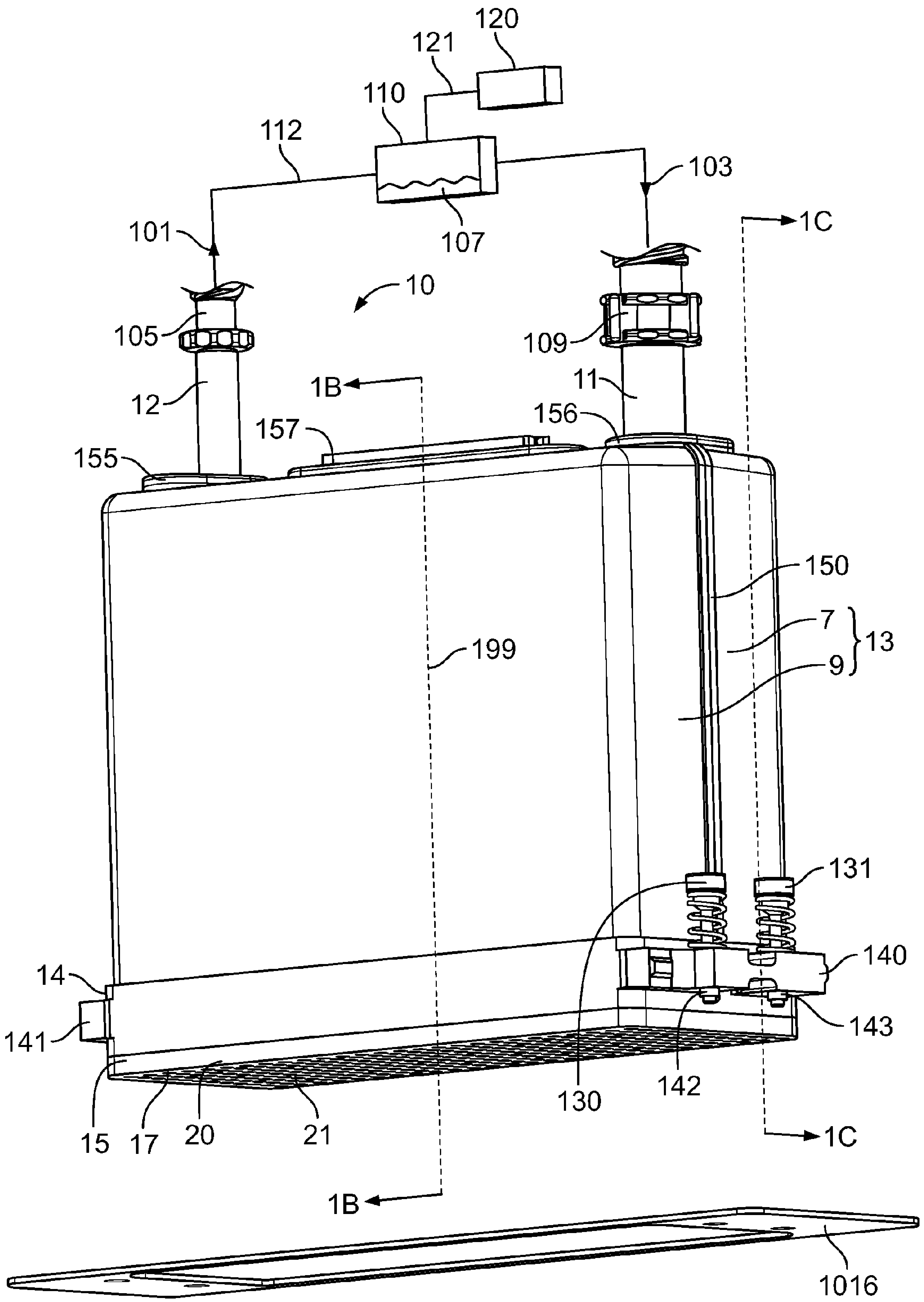

120
121
110
112
103
101
107
1C
10
105
109
12
1B
11
157
156
155
150
7
13
199
9
131
140
14
141
143
142
130
15
17
20
21
1C
1B
1016

FIG. 1A

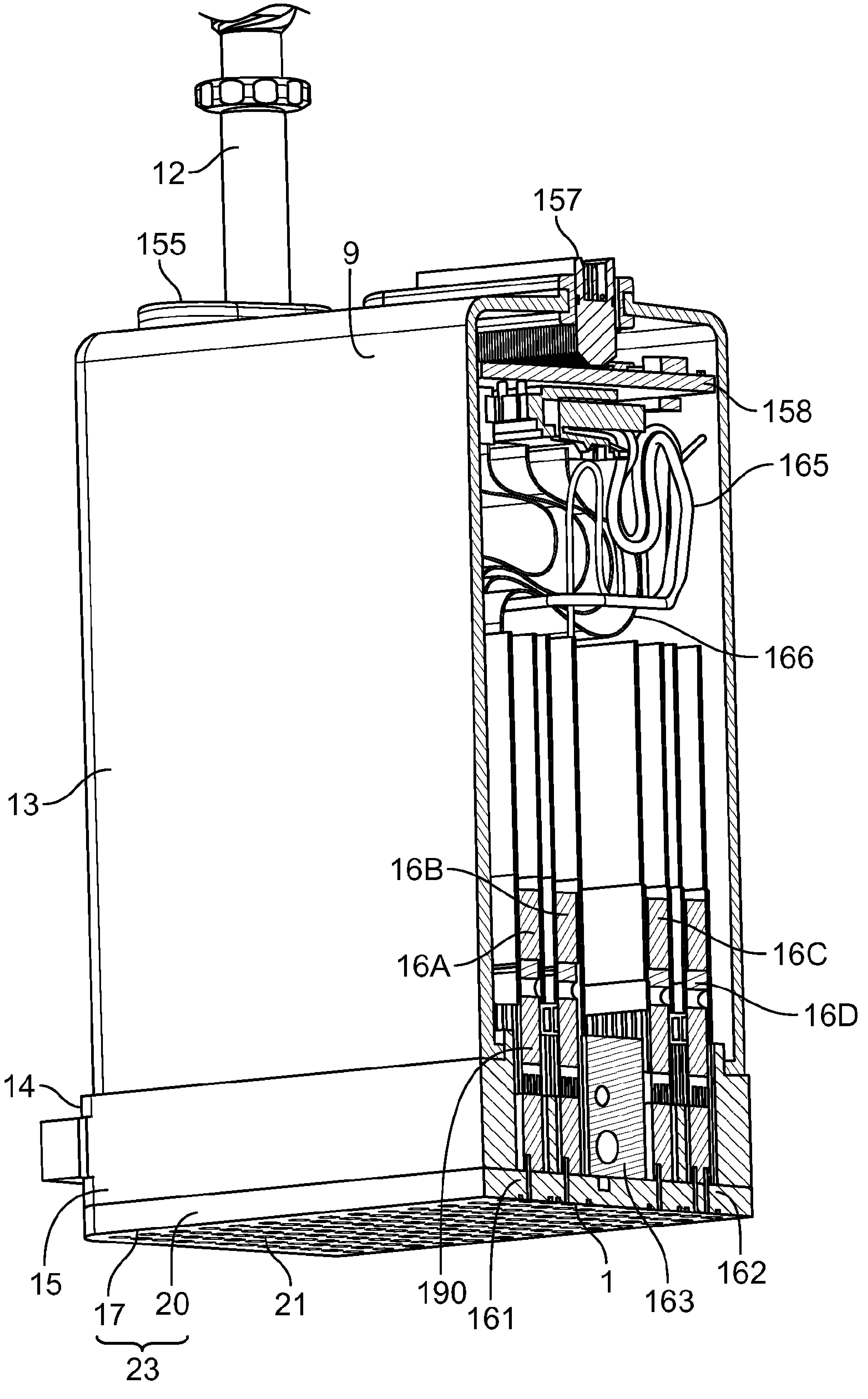

12
155
9
157
158
165
166
13
16B
16A
16C
16D
14
15
17
20
21
190
161
1
163
162
23

FIG. 1B

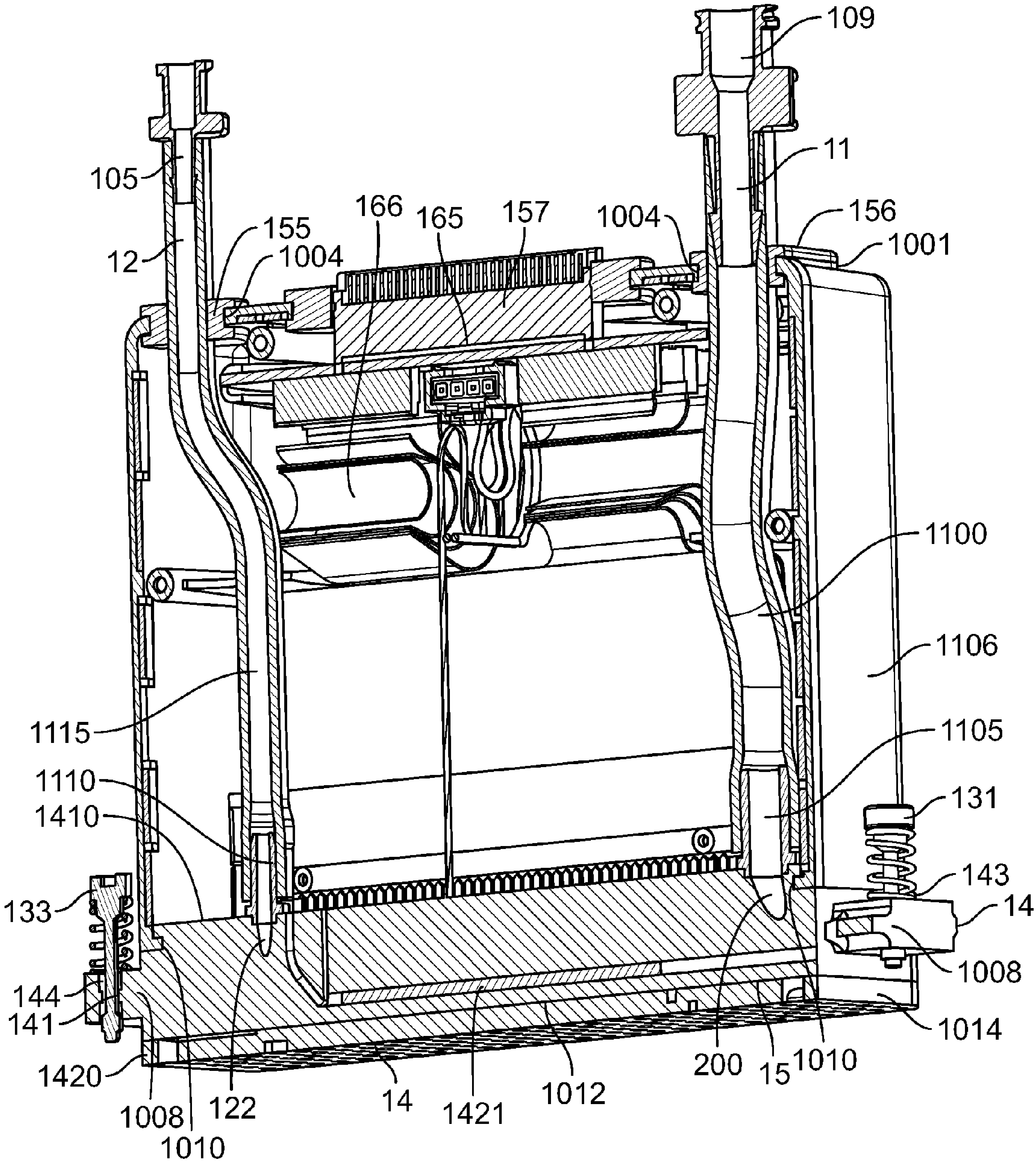

109
105
11
166
165
157
1004
156
155
1001
12
1004
1100
1106
1115
1105
1110
131
1410
143
140
133
1008
144
141
1014
1420
200
15
1010
1008
122
14
1421
1012
1010

FIG. 1C

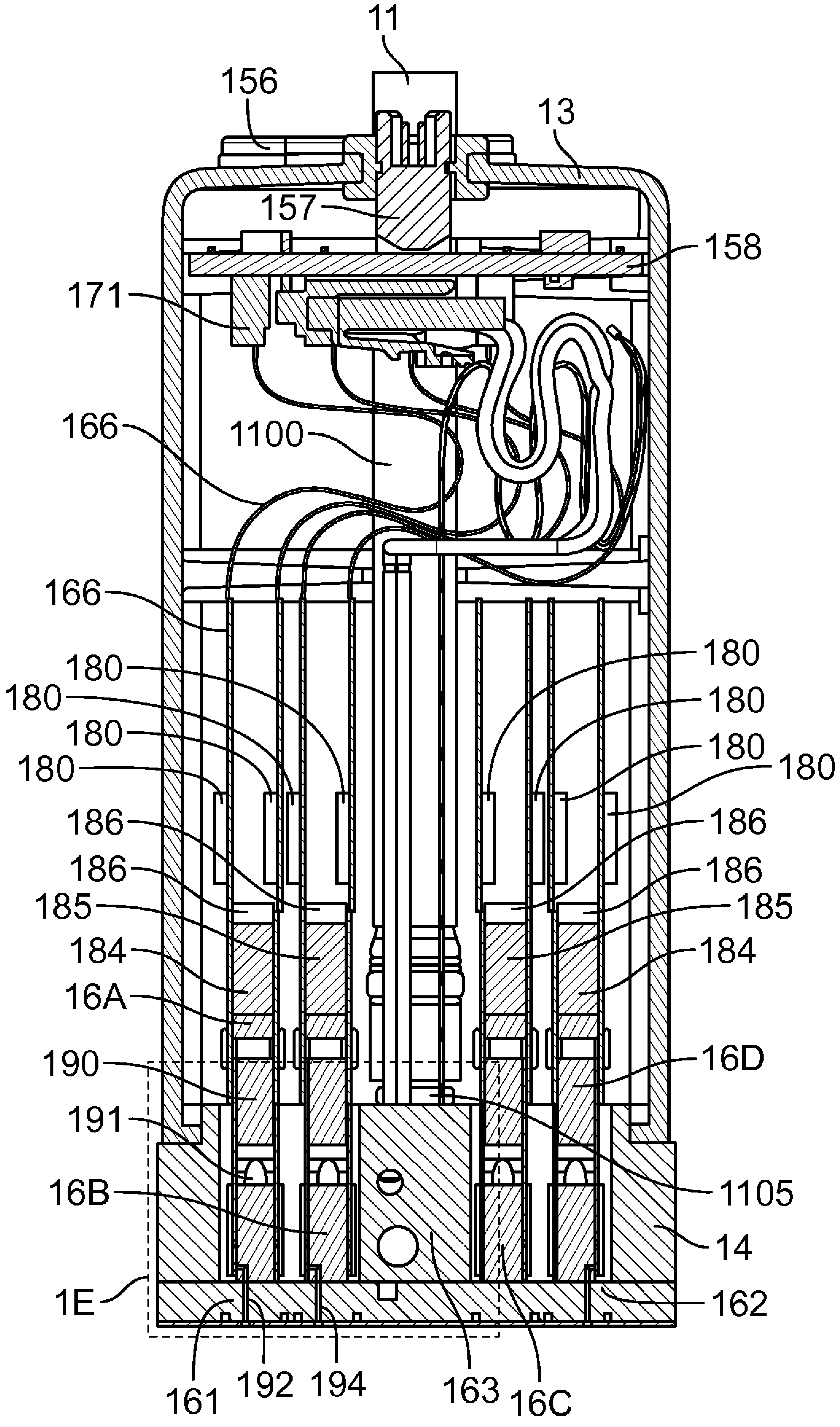

11
156
13
157
158
171
166
1100
166
180
180
180
180
180
180
180
180
186
186
186
186
185
185
184
184
16A
16D
190
191
1105
16B
14
1E
162
161
192
194
163
16C

FIG. 1D

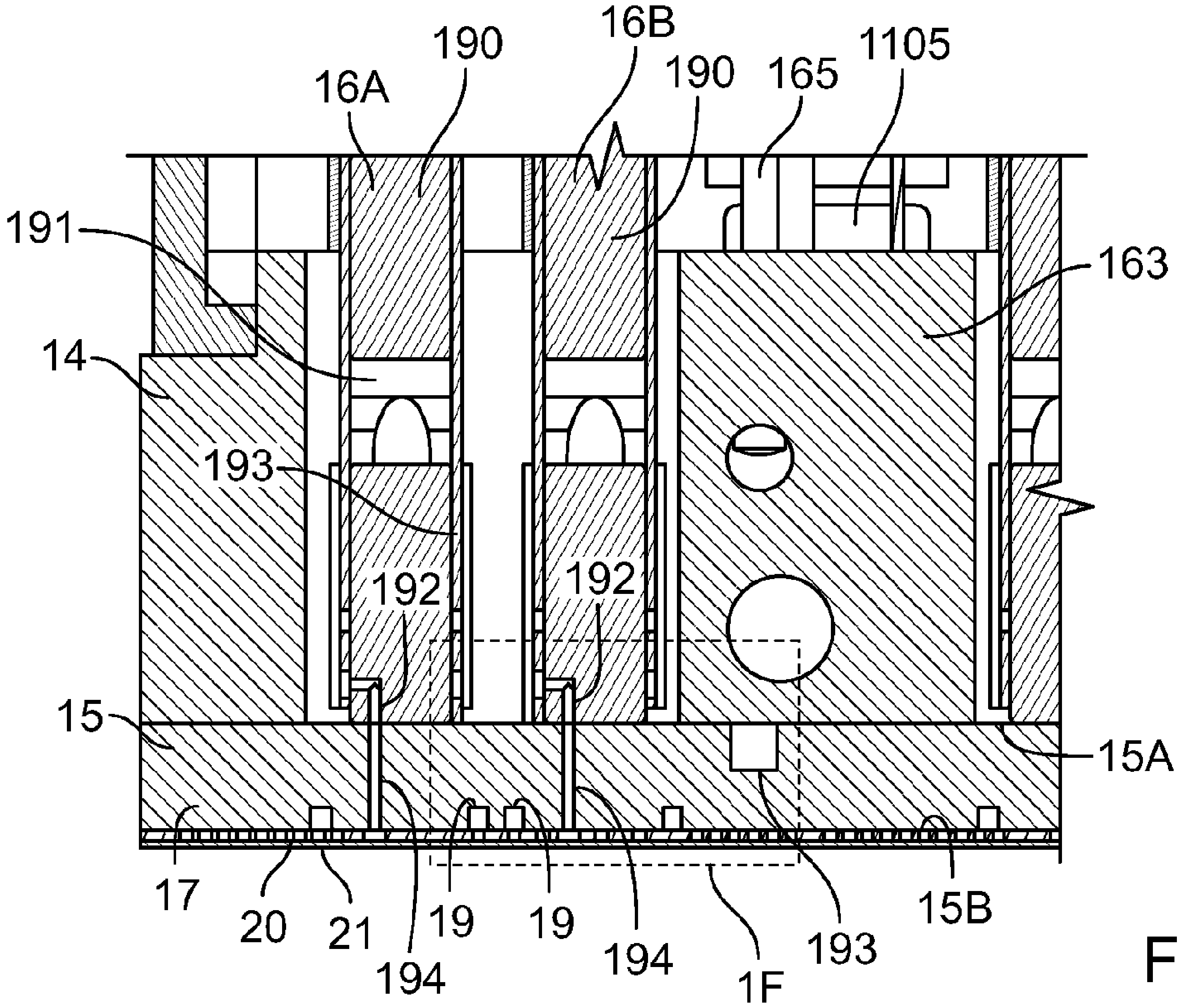

16A
190
16B
190
165
1105
191
163
14
193
192
192
15
15A
17
20
21
194
19
19
194
1F
193
15B

FIG. 1E

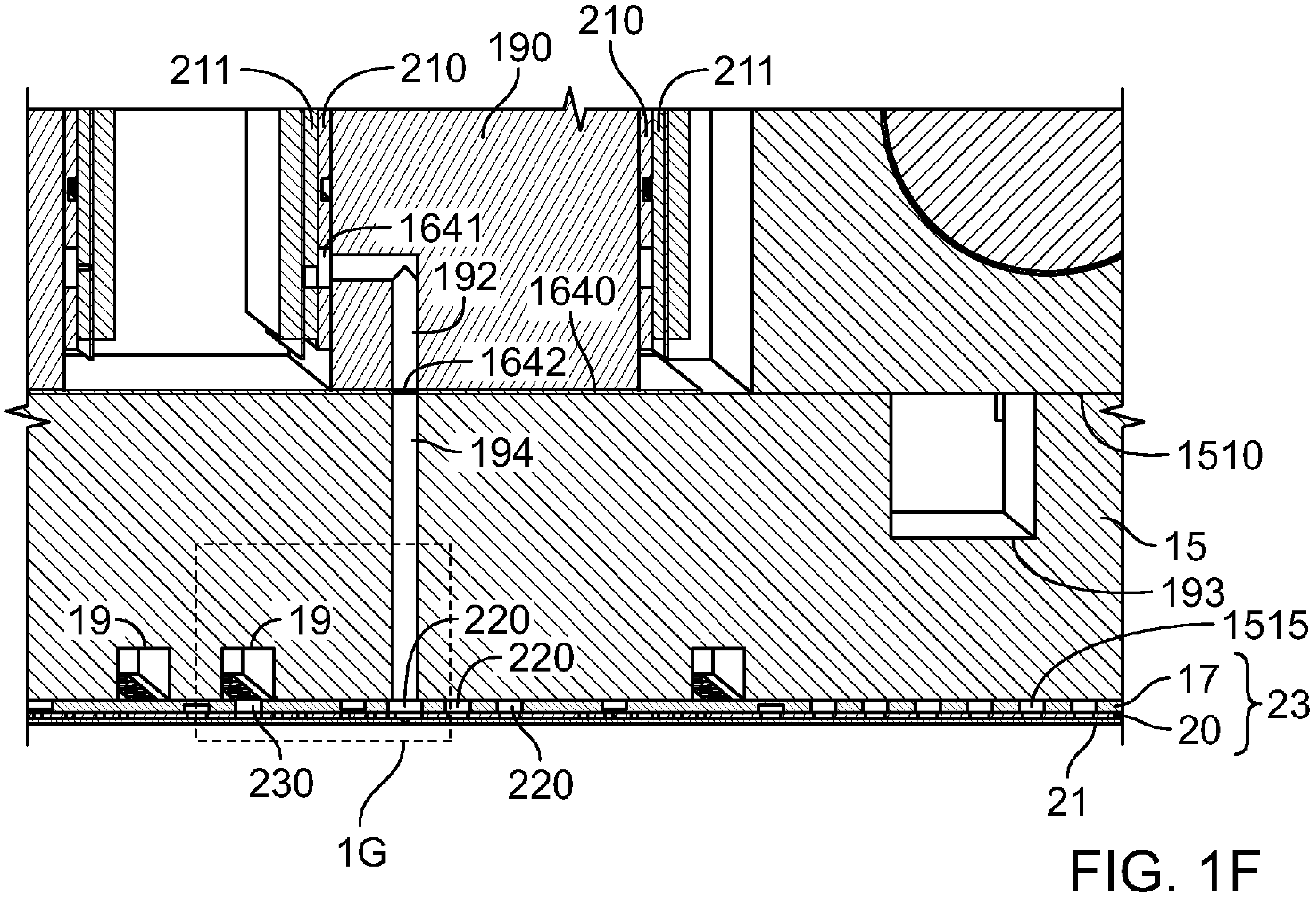

211
210
190
210
211
1641
192
1640
1642
194
1510
15
193
19
19
220
220
1515
17
23
20
230
220
21
1G

FIG. 1F

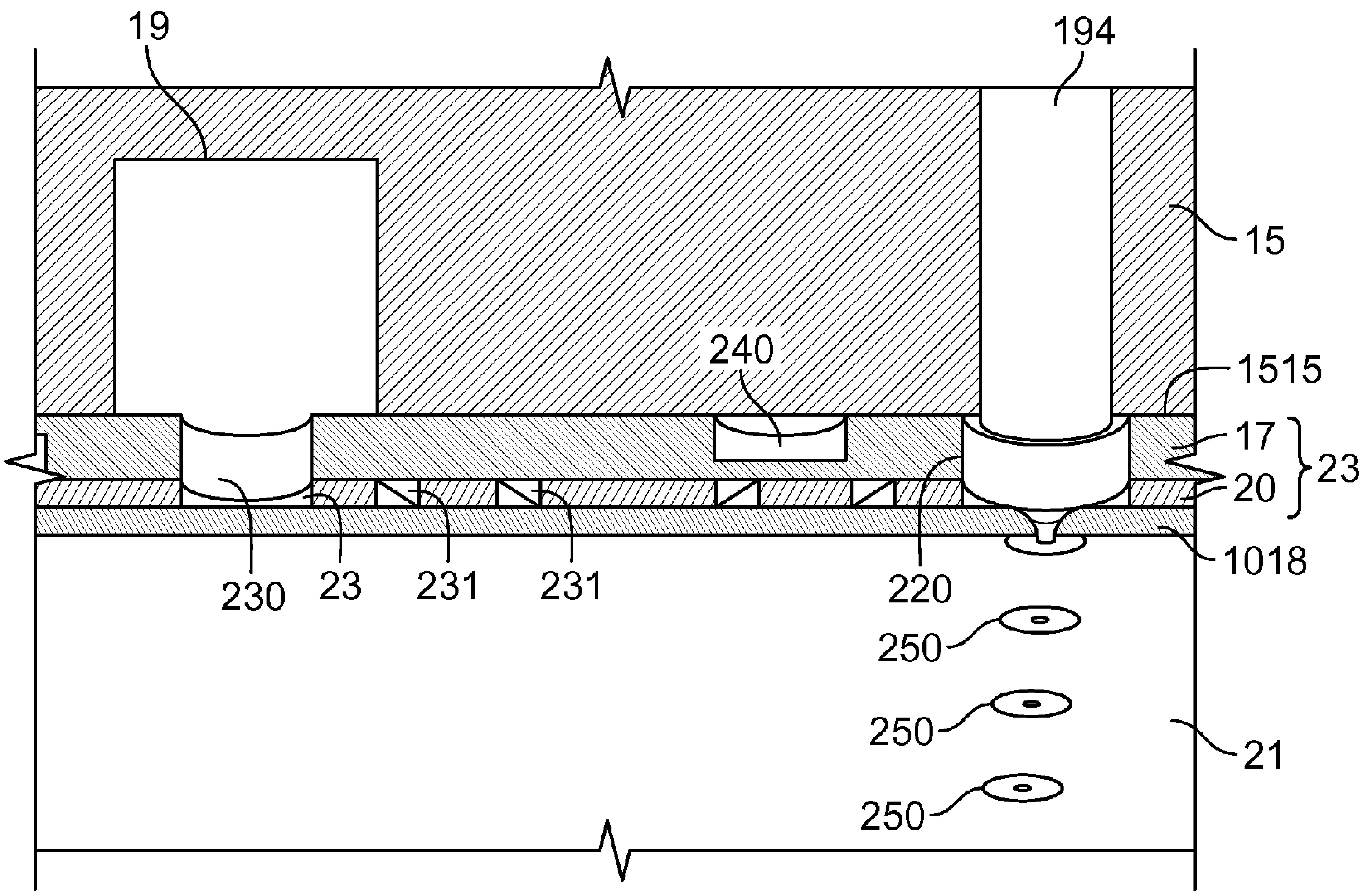

19
194
15
240
1515
17
23
20
1018
230
23
231
231
220
250
250
21
250

FIG. 1G

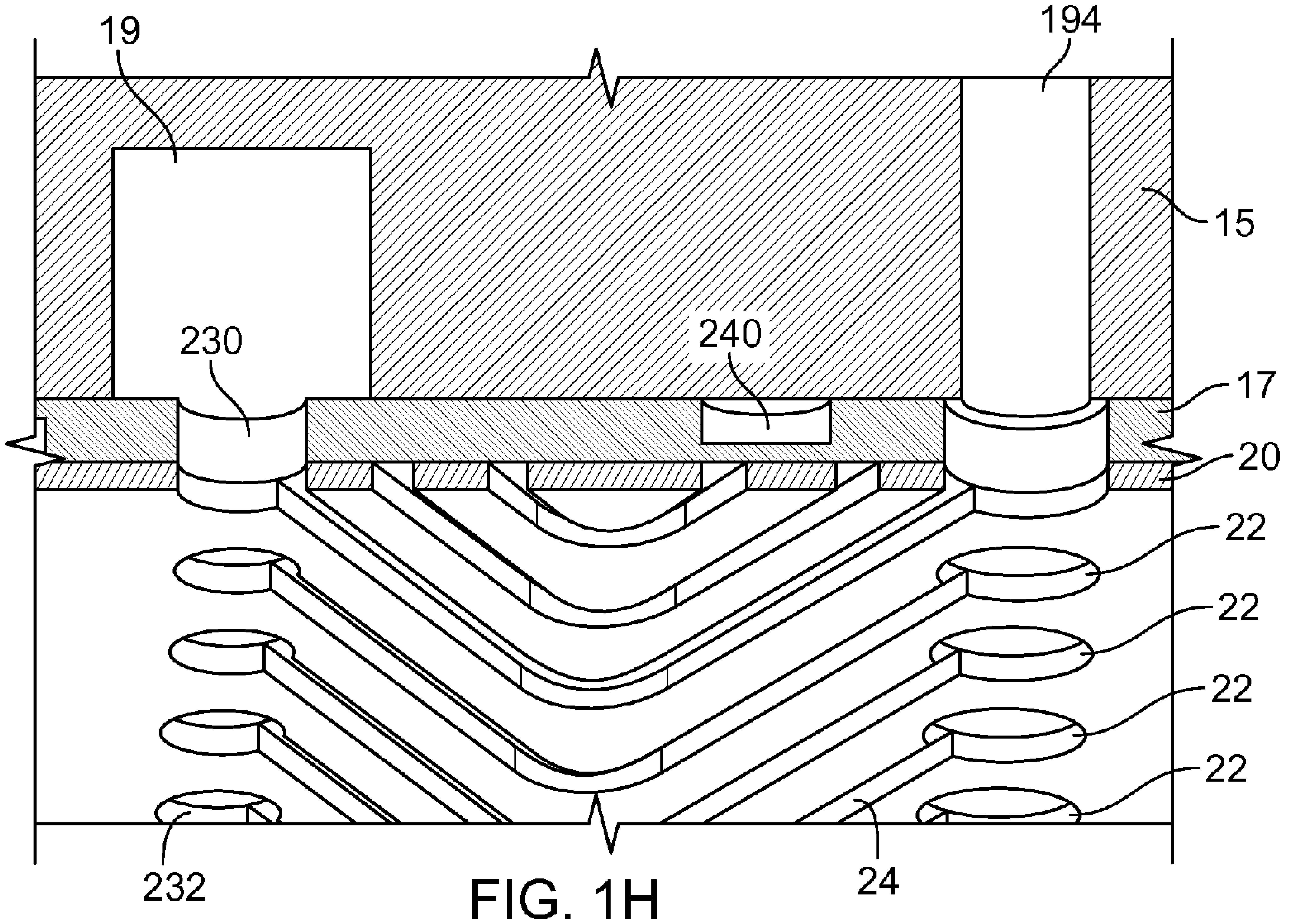

19
194
15
230
240
17
20
22
22
22
22
232
24

FIG. 1H

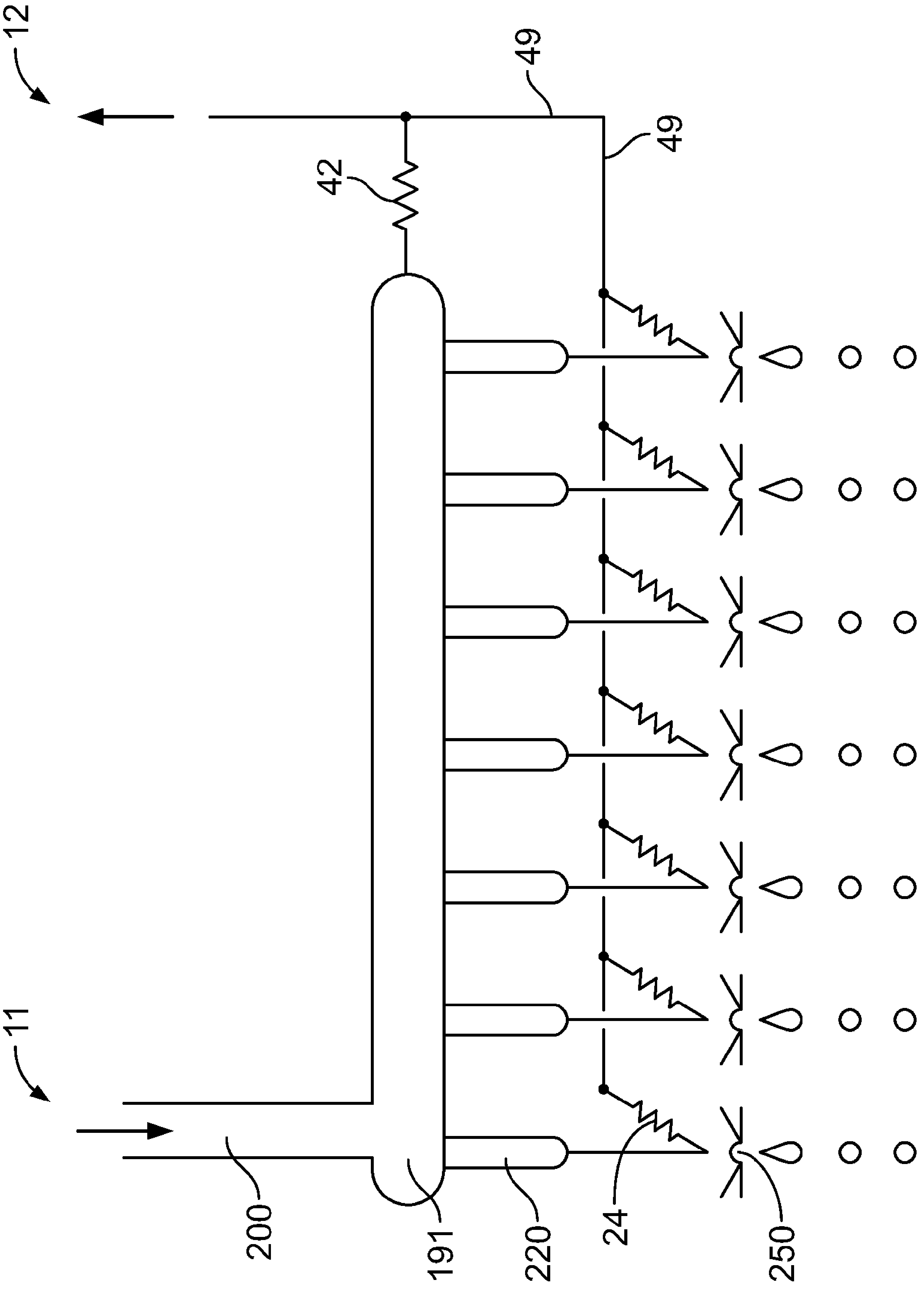


FIG. 2

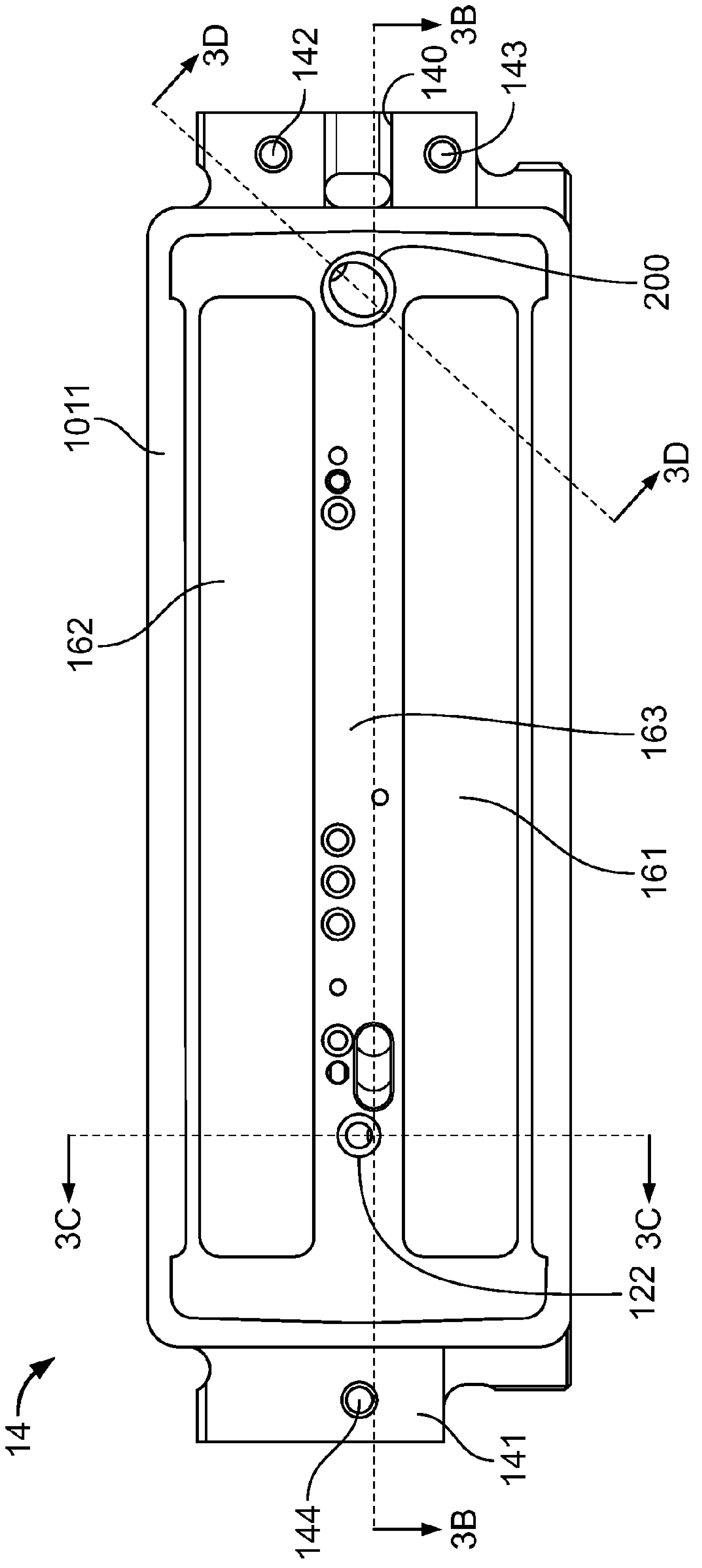

3D
142
140
3B
143
1011
200
3D
162
163
161
122
3C
3C
14
144
141
3B

FIG. 3A

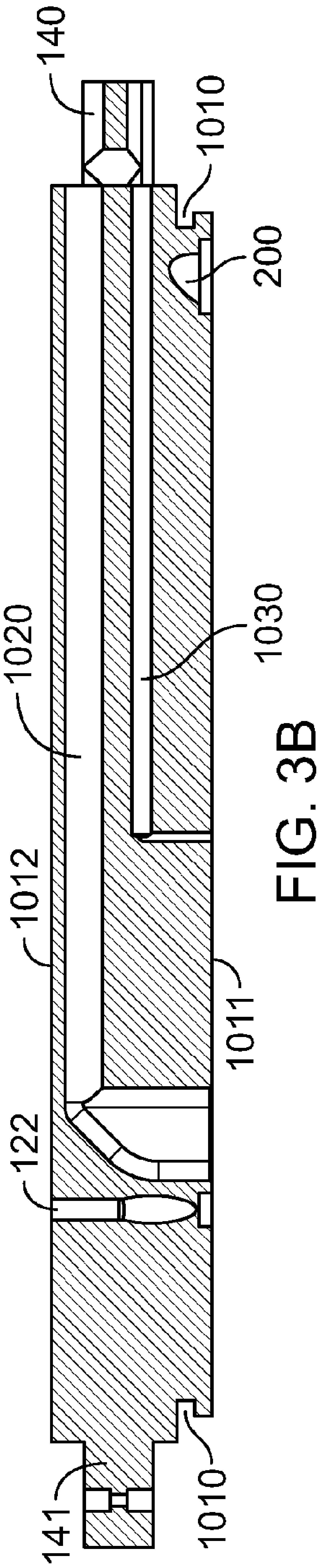

140
1010
200
1020
1030
1012
1011
122
141
1010

FIG. 3B

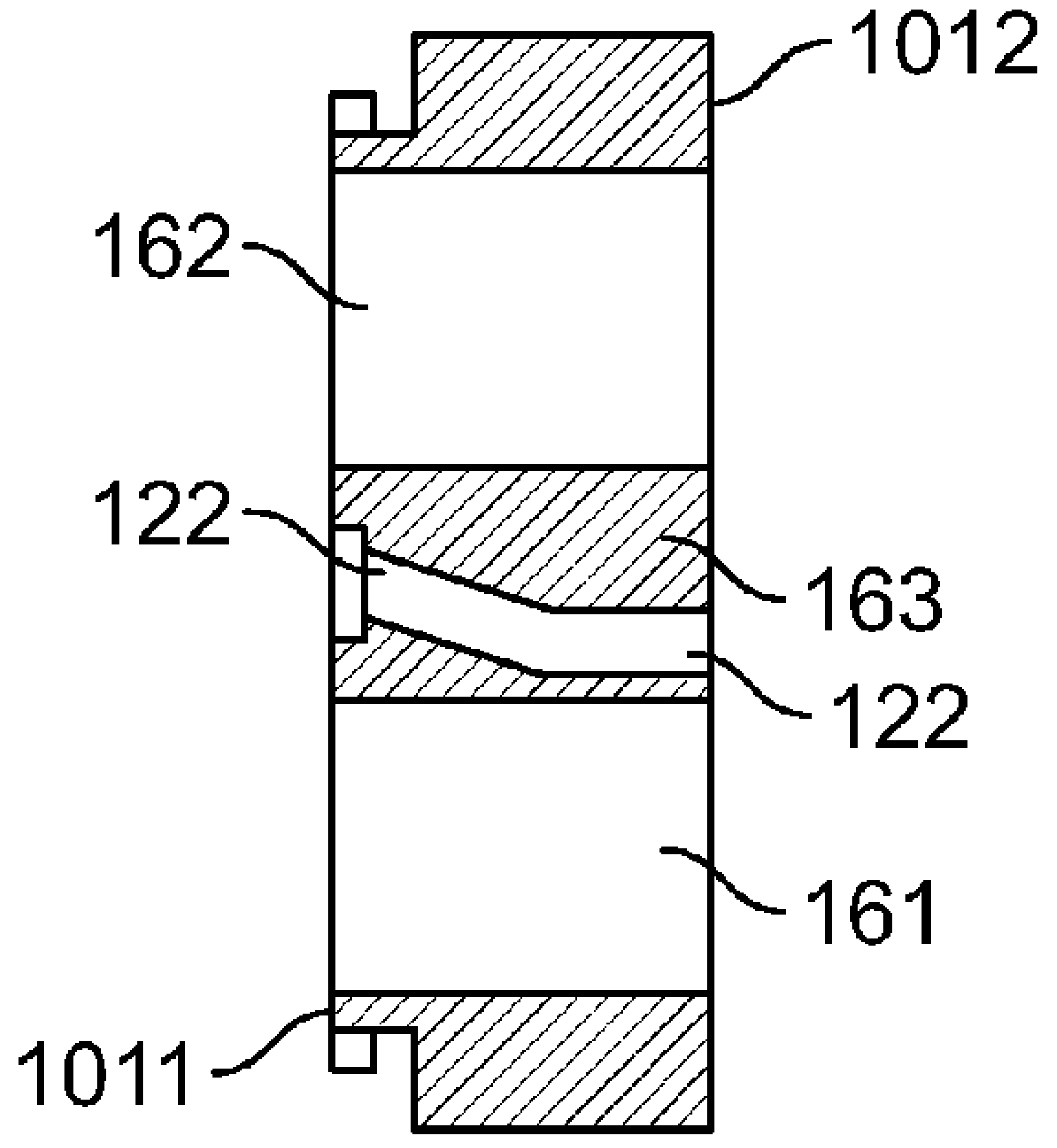


FIG. 3C

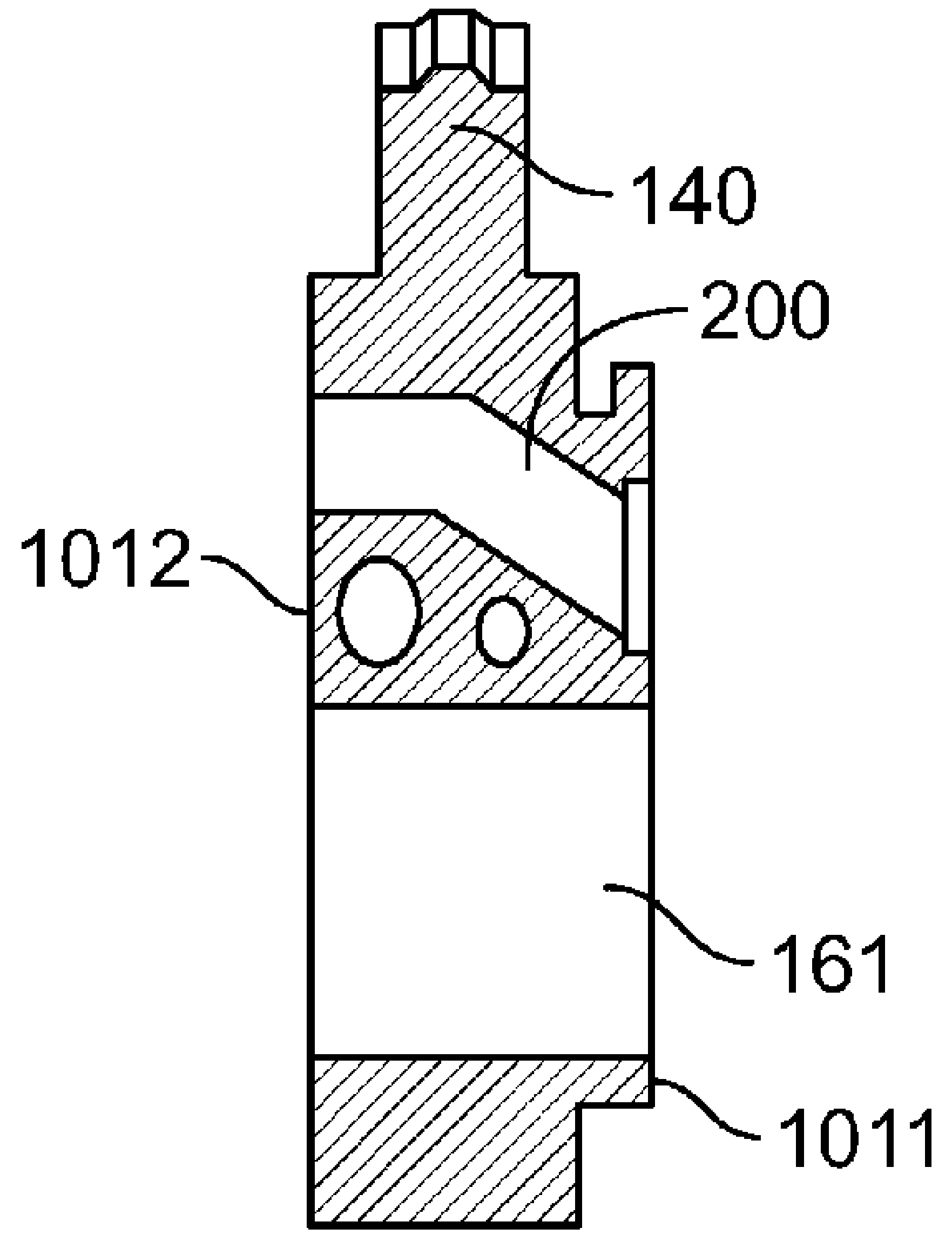


FIG. 3D

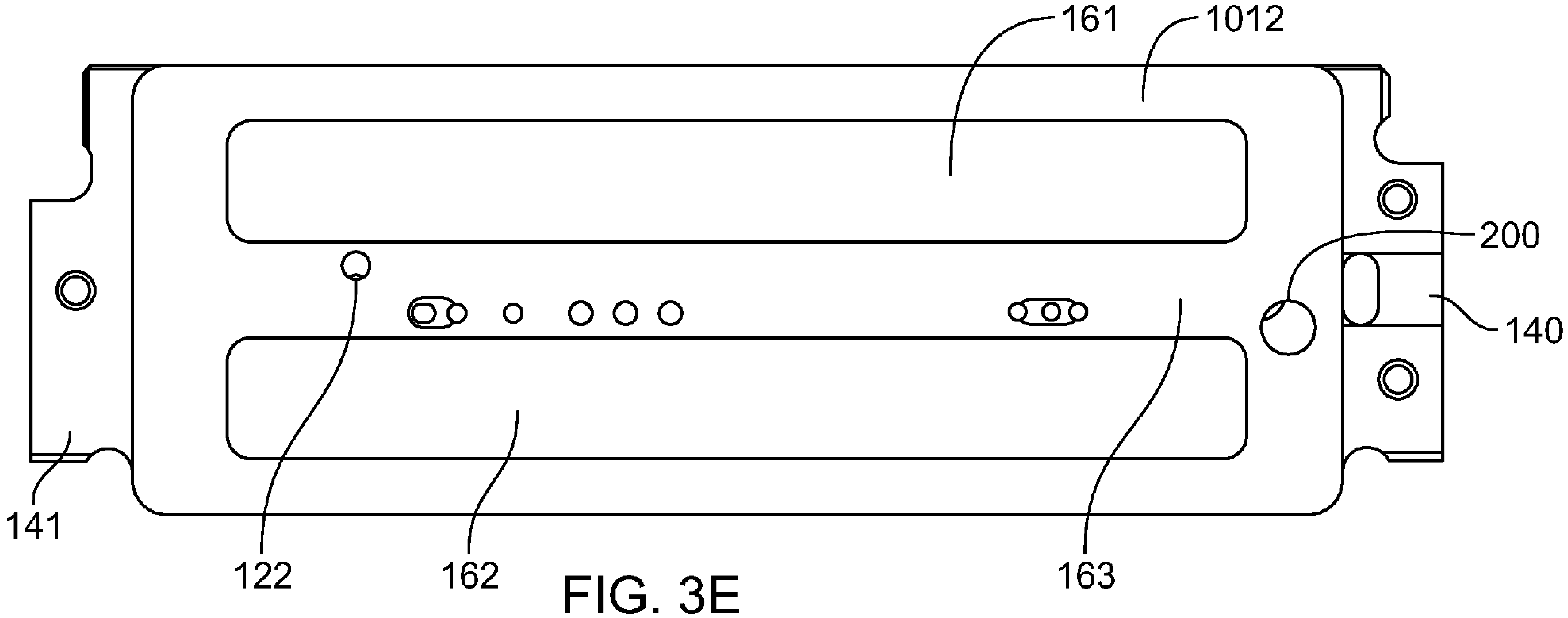


FIG. 3E

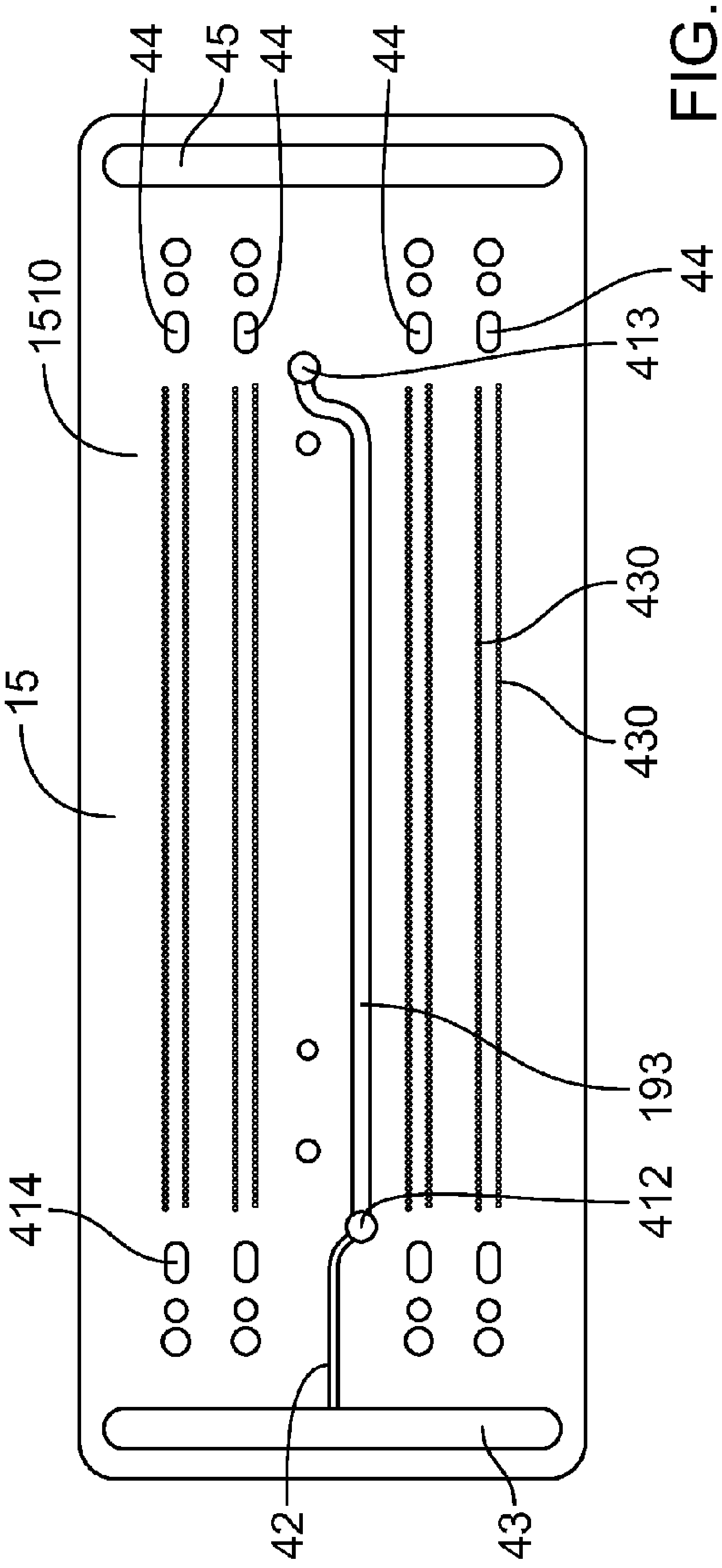

44
45
44
44
1510
44
413
15
430
430
193
414
412
42
43

FIG. 4A

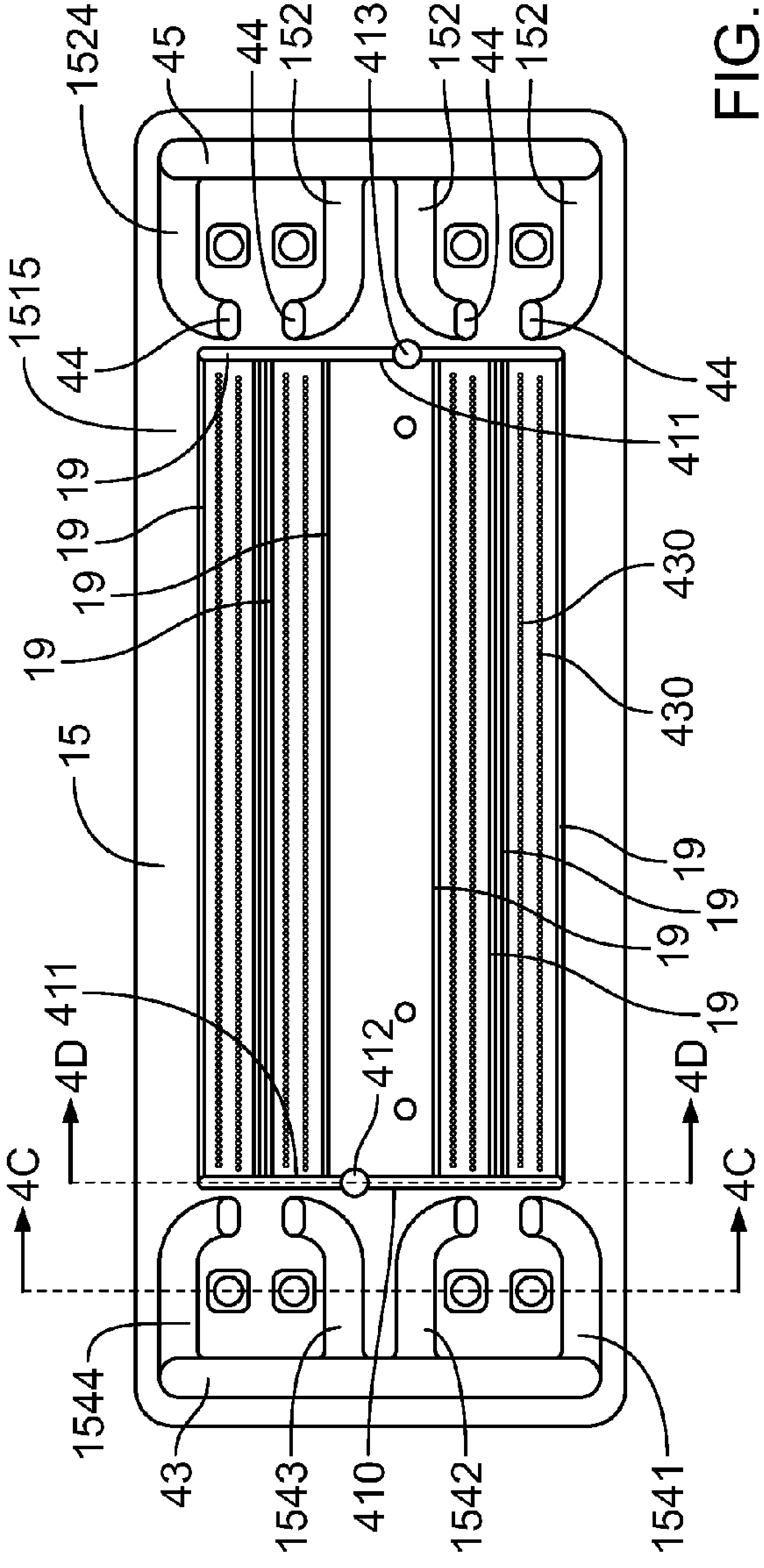

1524
45
44
1523
413
1522
44
1521
1515
44
44
411
19
19
19
19
19
15
430
430
19
19
19
19
4D
411
412
4D
4C
4C
1544
43
1543
410
1542
1541

FIG. 4B

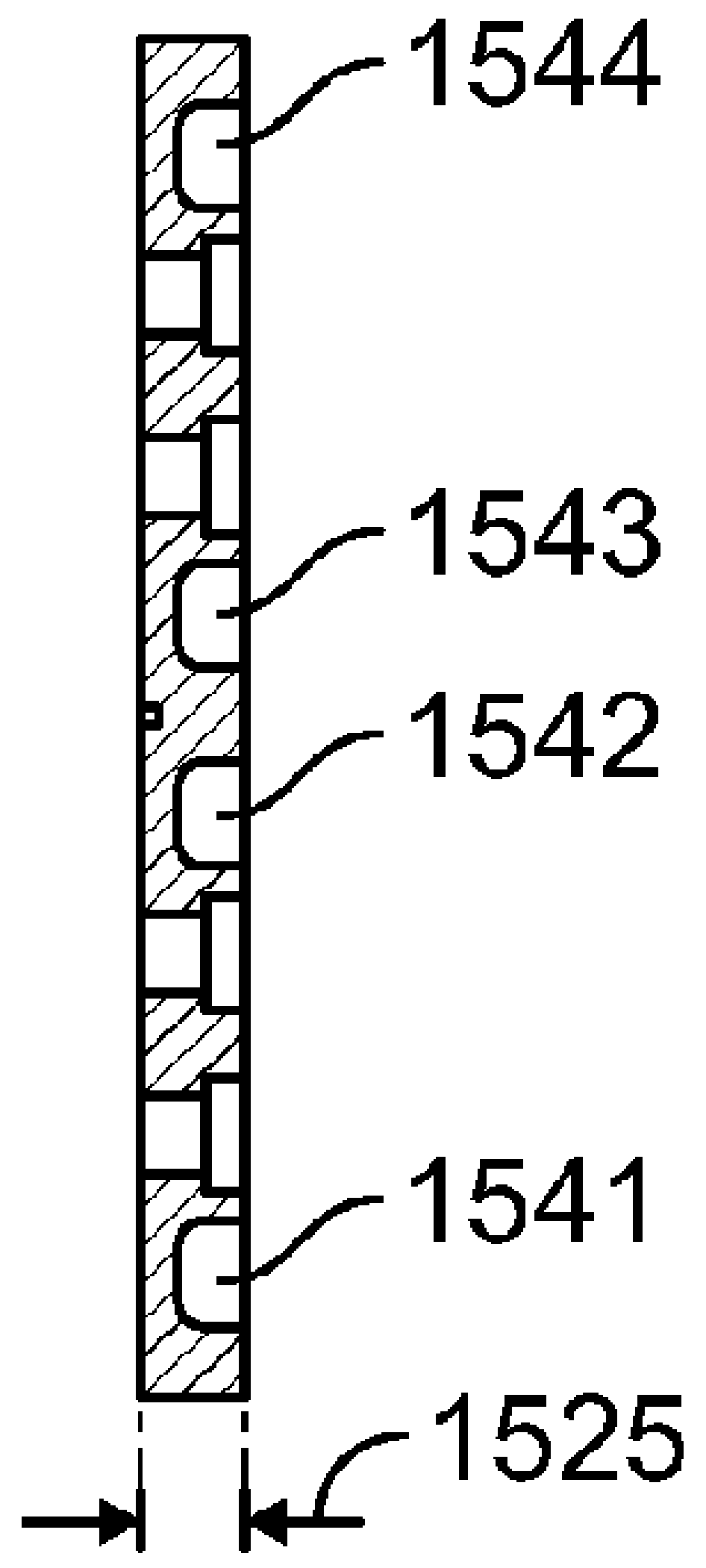


FIG. 4C

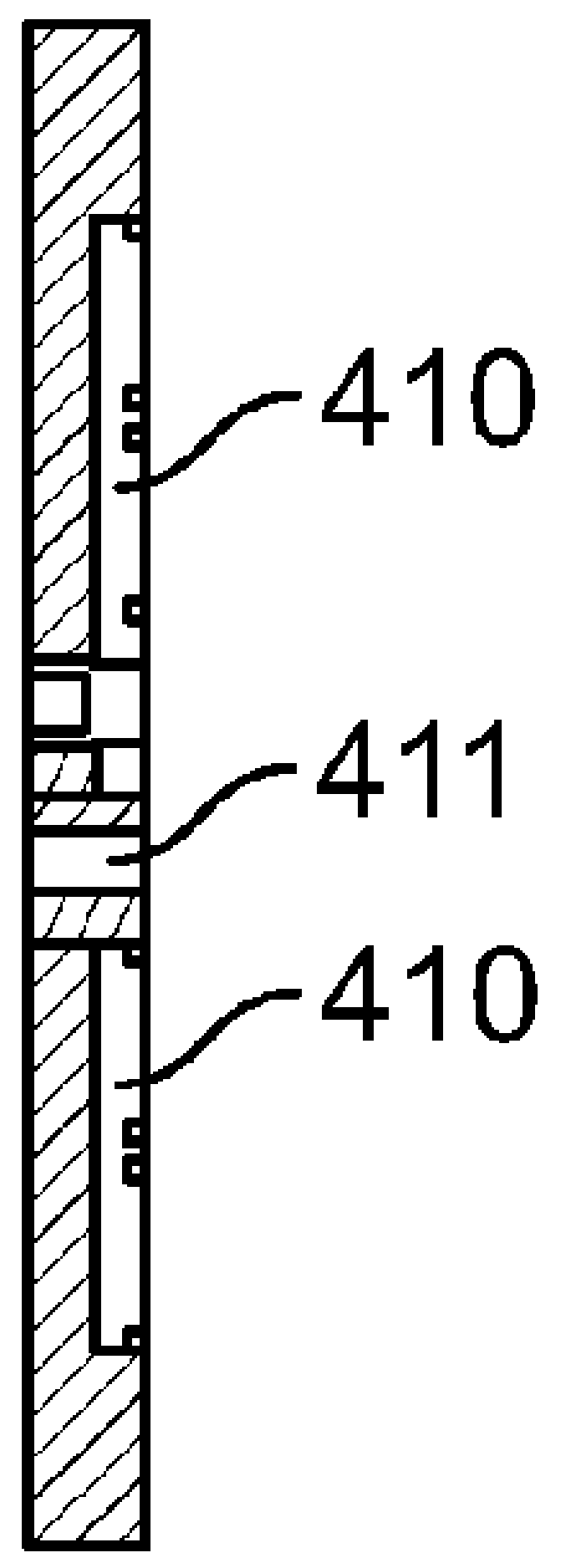


FIG. 4D

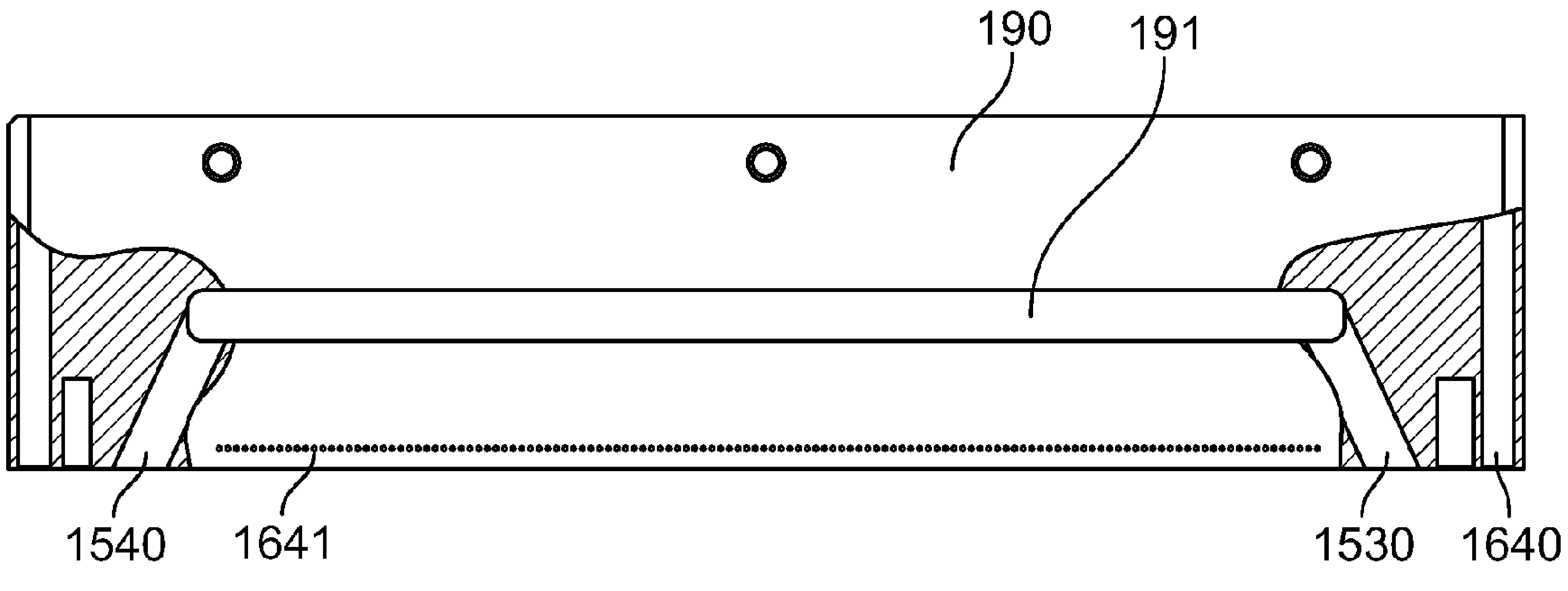


FIG. 4E

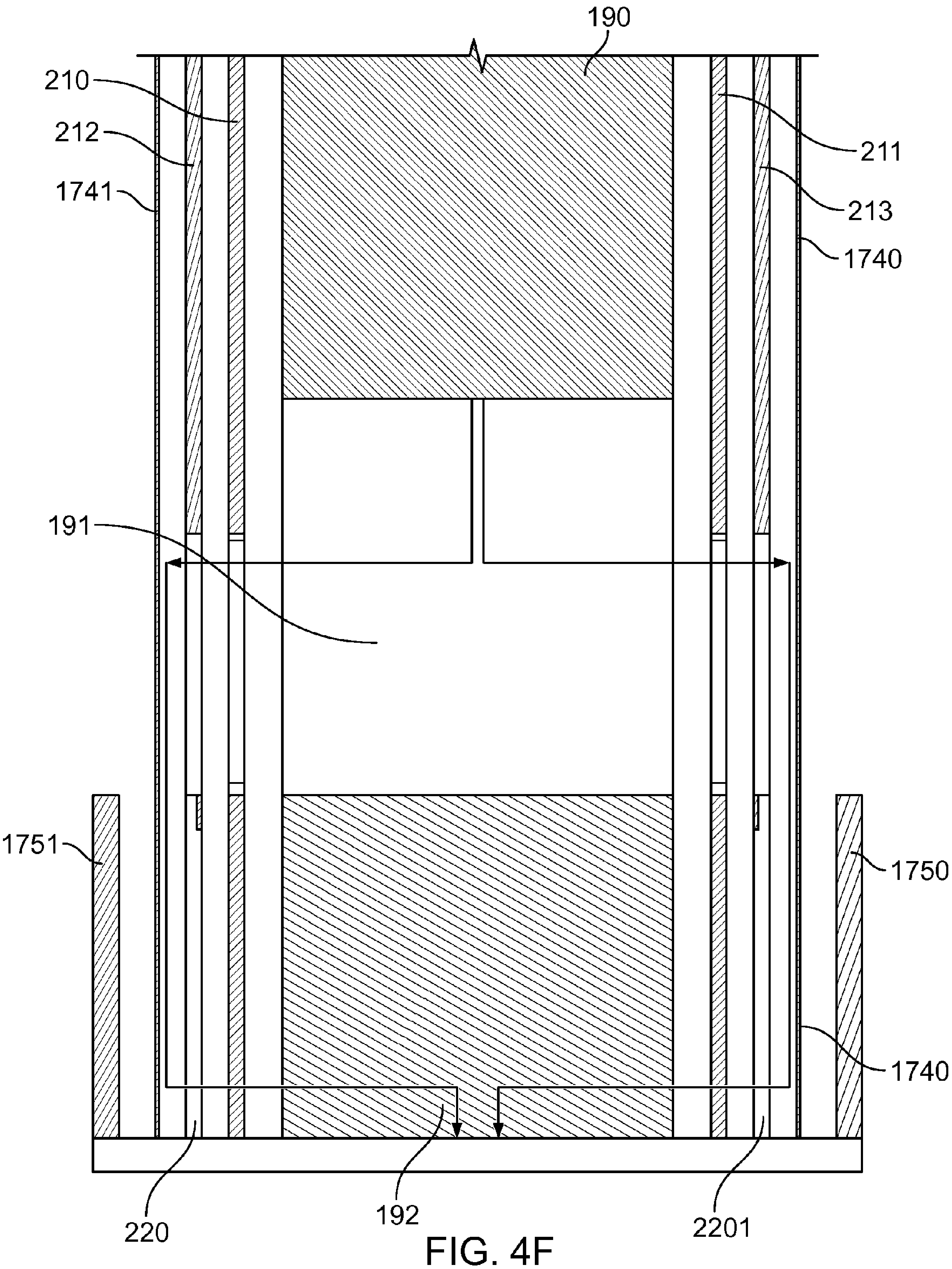


FIG. 4F

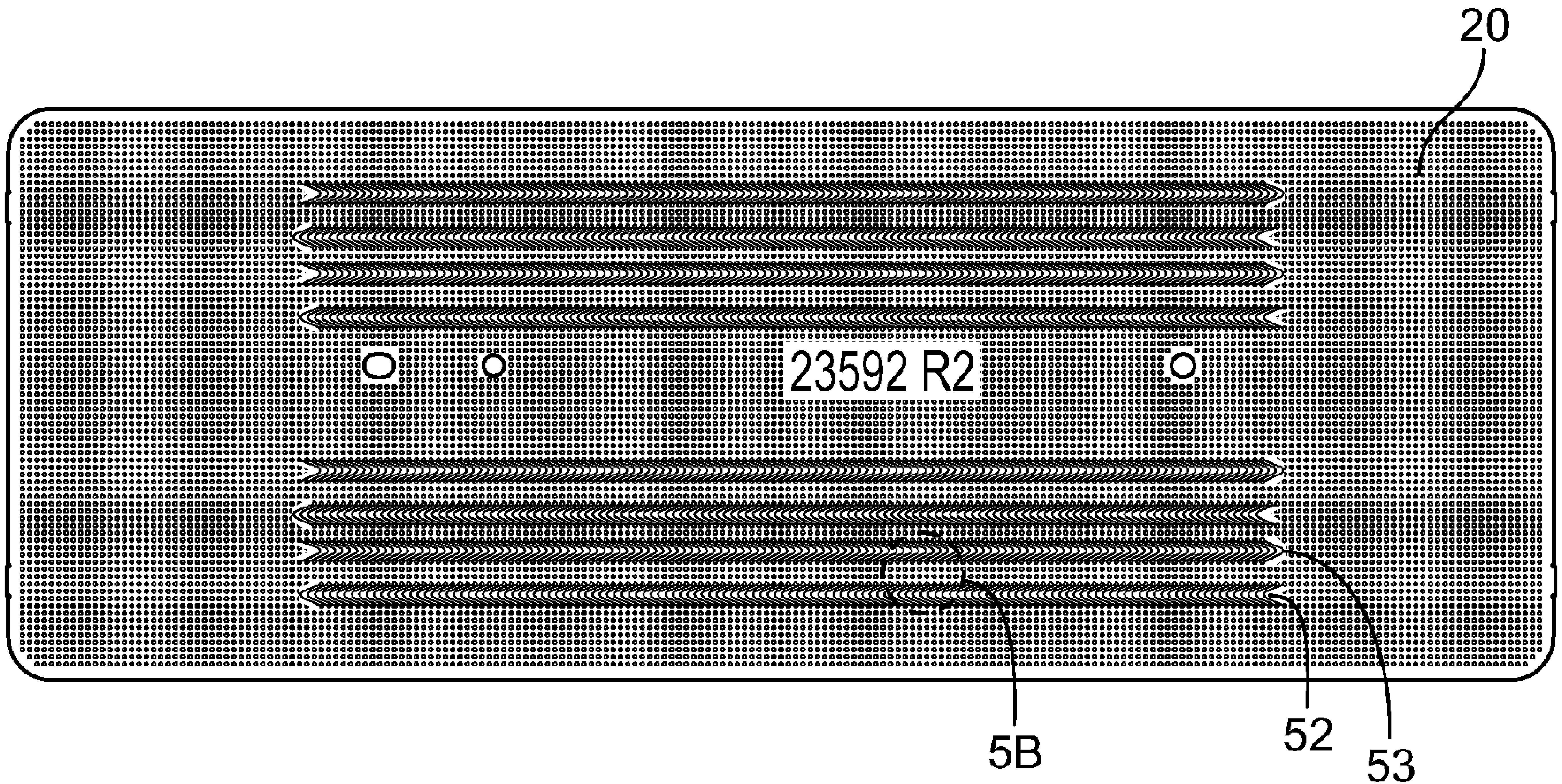


FIG. 5A

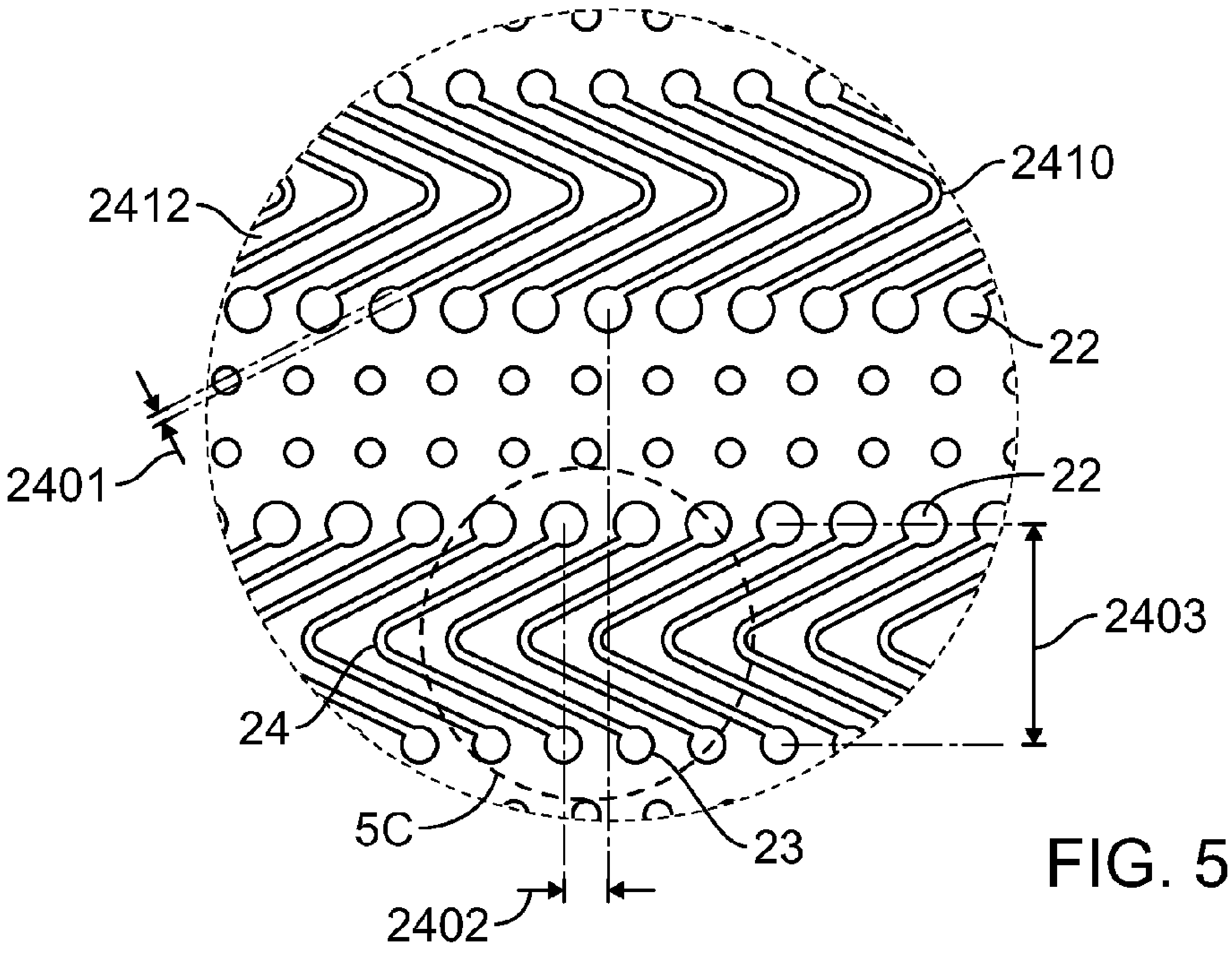


FIG. 5B

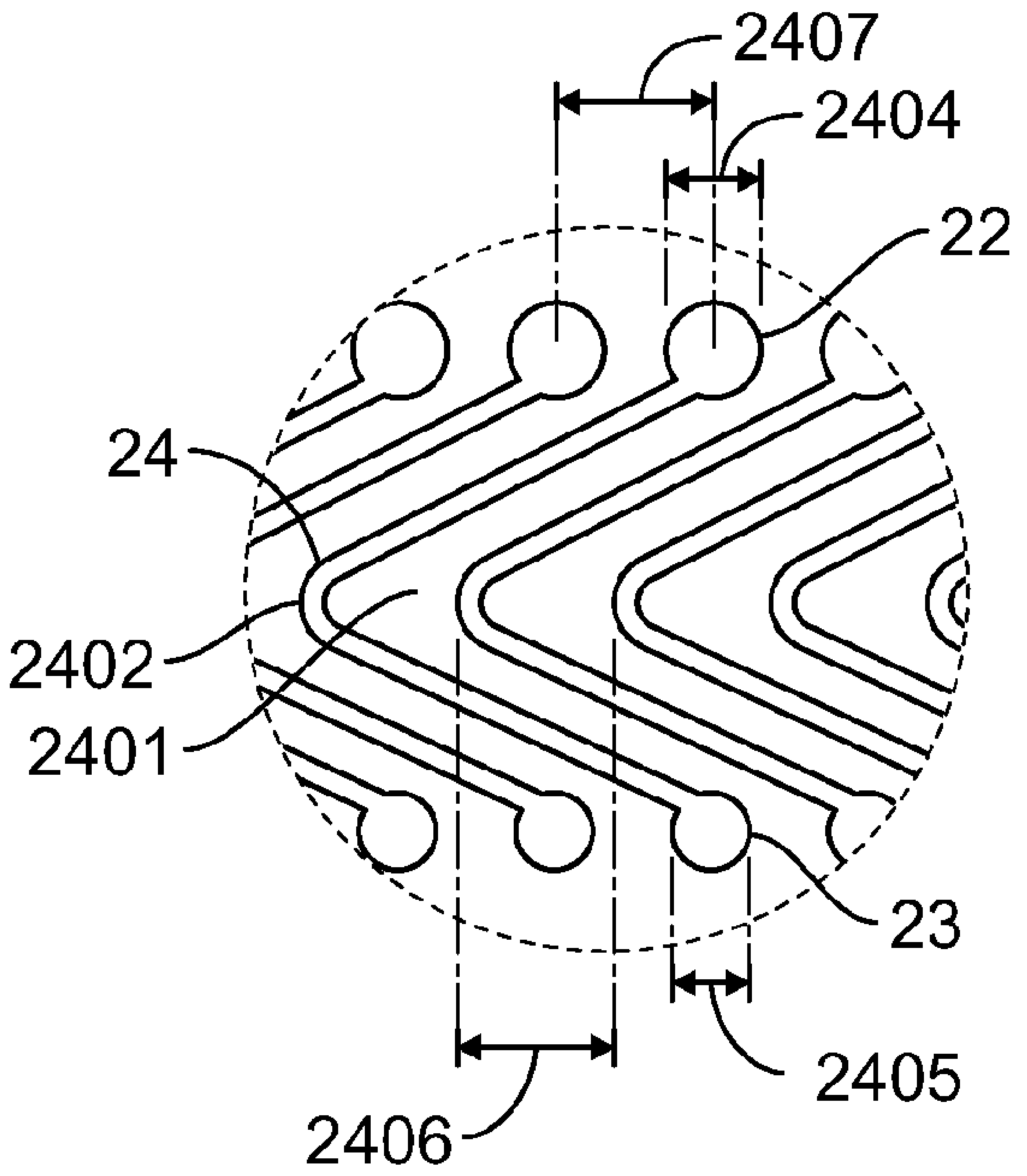


FIG. 5C

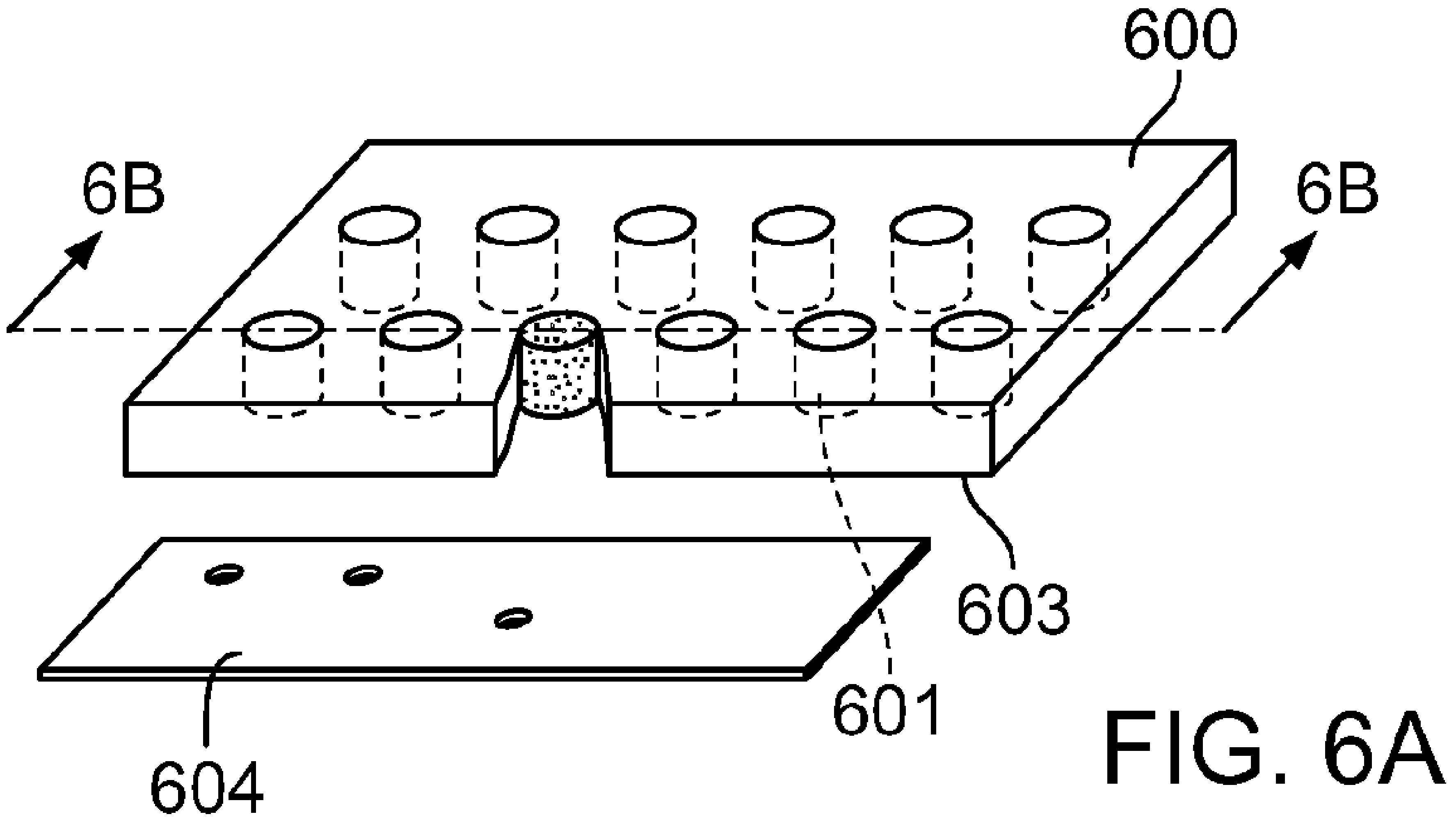


FIG. 6A

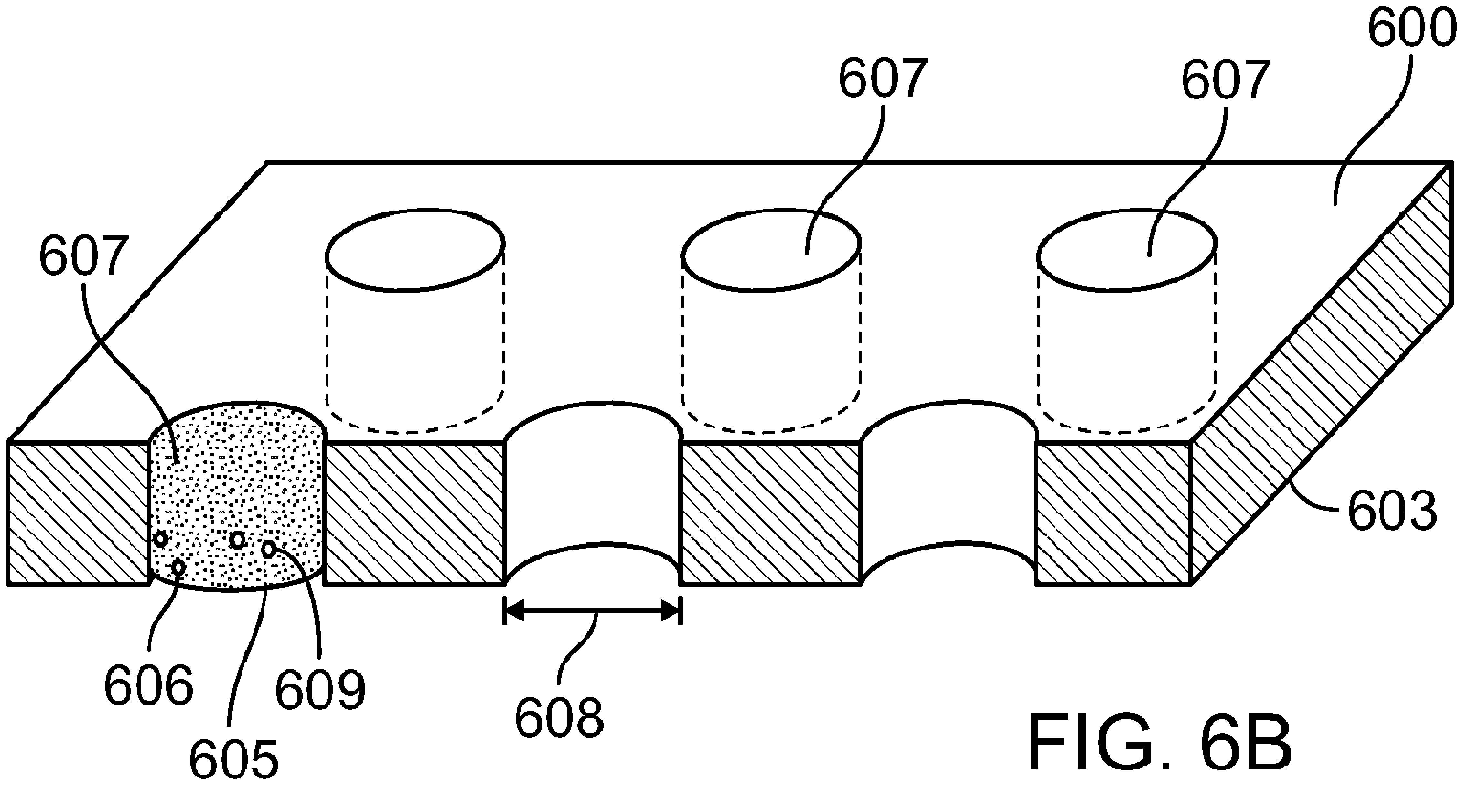


FIG. 6B

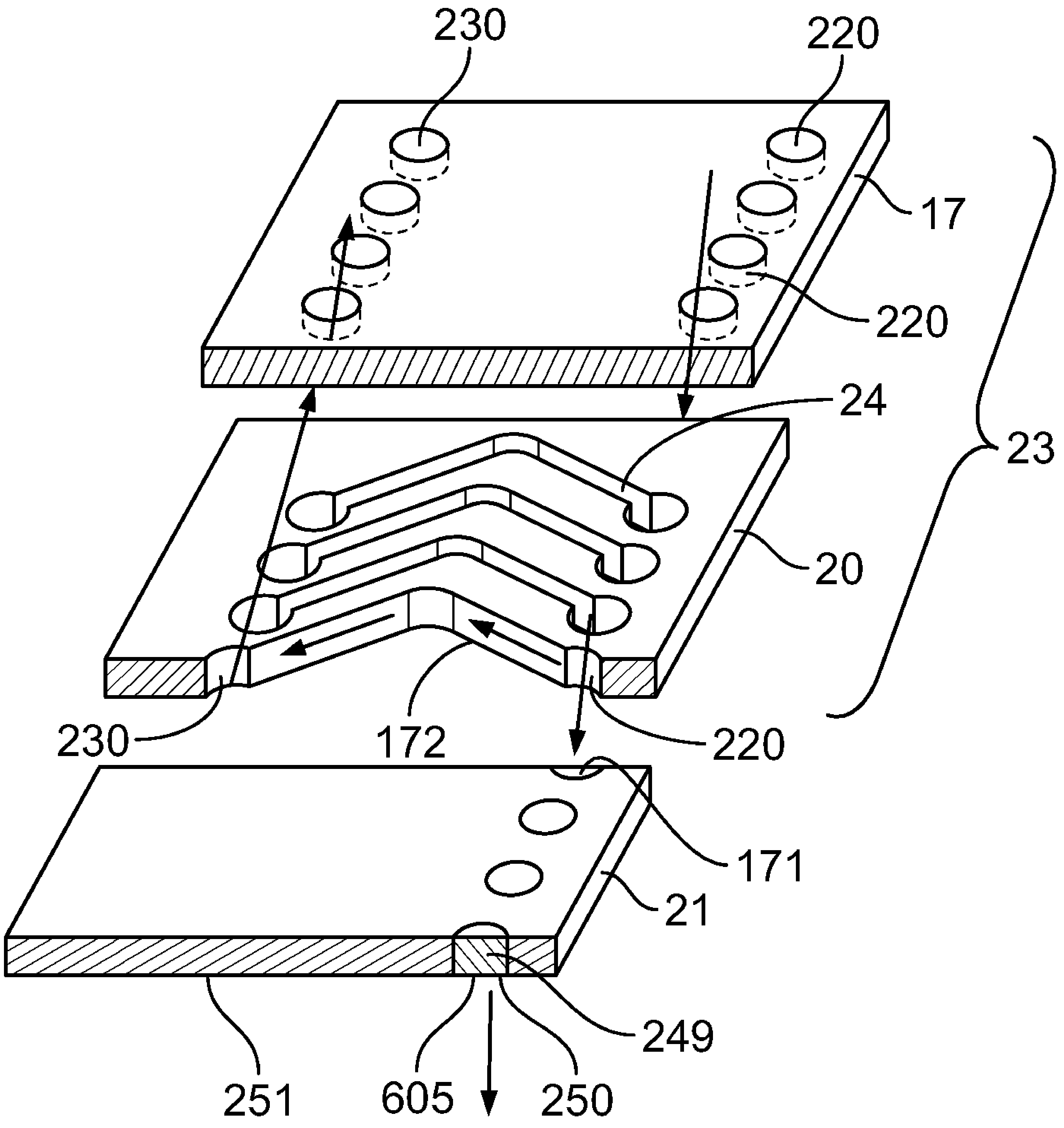


FIG. 7

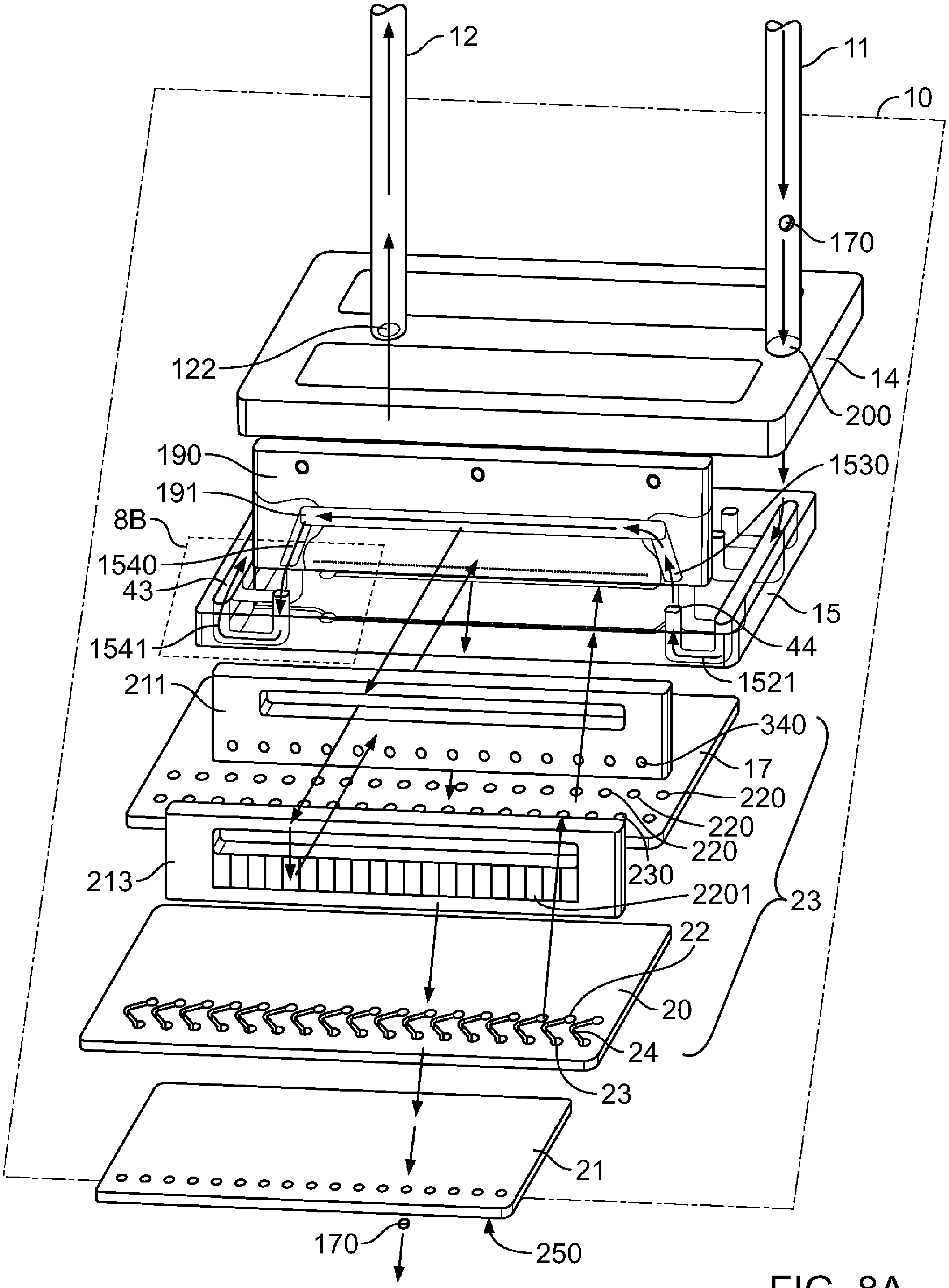

12
11
10
170
122
14
200
190
1530
191
8B
1540
43
15
1541
44
1521
211
340
17
220
220
220
230
213
2201
23
22
20
24
23
21
170
250

FIG. 8A

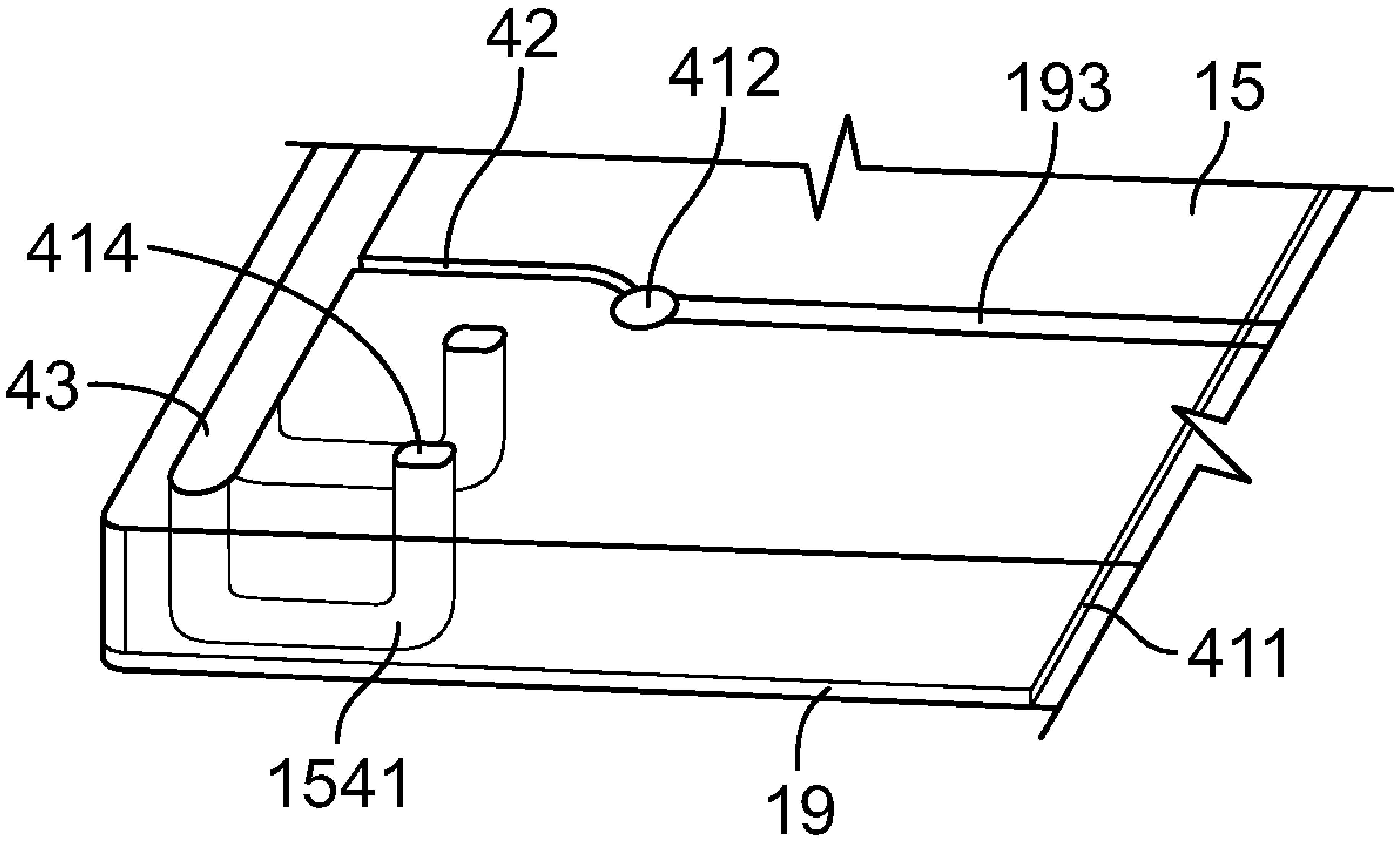


FIG. 8B

RECIRCULATION OF INK

This patent application is a continuation of and claims the benefit of the priority to U.S. patent application Ser. No. 14/268,491, filed May 2, 2014, now issued U.S. Pat. No. 9,144,993, which is a continuation of and claims the benefit of priority to U.S. patent application Ser. No. 13/786,360, filed Mar. 5, 2013, now issued U.S. Pat. No. 8,752,946, which claims the benefit of priority to U.S. Provisional Patent Application No. 61/606,709, filed on Mar. 5, 2012, and U.S. Provisional Patent Application No. 61/606,880 filed on Mar. 5, 2012, the contents of which are hereby incorporated by reference in their entirety. This application incorporates U.S. application Ser. No. 13/786,154, filed on Mar. 5, 2013, by reference in its entirety.

TECHNICAL FIELD

This description relates to recirculation of ink.

The characteristics of ink at a nozzle of an inkjet, for example, can change during the time that elapses between print jobs. When the inkjet is first fired for the subsequent print job, the ink drop that is ejected can have characteristics different from subsequent ink drops that are formed from fresh ink. Recirculating ink near the nozzle can keep the ink fresh and ready for jetting during the time that elapses between print jobs. A nozzle plate, which includes a series of nozzle openings or orifices, often is the last element encountered by the ink before it is ejected from a printhead assembly. The nozzle plate contains nozzle tubes that extend through the thickness of the nozzle plate and end at the exposed face of the nozzle plate.

SUMMARY

In general, in an aspect, an apparatus includes an inkjet assembly having inkjet nozzles through each of which ink flows at a nominal flow rate as it is ejected from the nozzle onto a substrate. Ink is held under a nominal negative pressure associated with a characteristic of a meniscus of the ink in the nozzle when ejection of ink from the nozzle is not occurring. The apparatus includes recirculation flow paths, each flow path having a nozzle end at which it opens into one of the nozzles and another location spaced from the nozzle end that is to be subjected to a recirculation pressure lower than the nominal negative pressure so that ink is recirculated from the nozzle through the flow path at a recirculation flow rate. Each recirculation flow path has a fluidic resistance between the nozzle end and the other location such that a recirculation pressure at the nozzle end of the flow path that results from the recirculation pressure applied at the other location of the flow path is small enough so that any reduction in flow rate below the nominal flow rate when ink is being ejected is less than a threshold, or a change in the nominal negative pressure when ink is not being ejected is less than a threshold, or both.

Implementations may include one or more of the following features. The nominal negative pressure is ten times a magnitude of a meniscus pressure formed by a fluid at the nozzles. The nominal negative pressure is between 10-40 inches of water (inwg). The recirculation flow paths direct a fluid from the inkjet assembly into an external fluid reservoir. The fluidic resistance is defined in a nozzle recirculation plate. Each of the fluidic resistance includes V-shape channels defined in the nozzle recirculation plate. Each of the fluidic resistance is 5 $(\text{dyne/cm}^2)/(\text{cm}^3/\text{sec}))$. The recirculation flow paths direct a portion of fluid within the inkjet assembly away from the inkjet nozzles. The recirculation flow rate is 10% of the nominal jetting flow rate. A length of the V-shape channel is a first multiple of a manufacturing tolerance of the channel. A width of the V-shape channel is a second multiple of the manufacturing tolerance of the channel. The first multiple is much greater than the second multiple. A radius of curvature at a bend in the V-shape channel is large enough to prevent fluidic reflections at the bend. The apparatus further includes a second recirculation flow path that extends from a refill chamber, the second recirculation flow path from the refill chamber having a second fluidic resistance. The fluidic resistance between the nozzle end and the other location is within ±50% of the second fluidic resistance. The refill chamber is defined in a body of the inkjet assembly. The body includes carbon. The second recirculation flow path directs fluid out of the inkjet assembly. The inkjet assembly further includes an integrated recirculation manifold. The integrated recirculation manifold is in fluidic communication with the recirculation flow paths and the second recirculation flow path. The nominal negative pressure is applied through the integrated recirculation manifold. The recirculation flow paths of the nozzles and the second recirculation flow path are fluidically connected in parallel. The apparatus further includes a nozzle recirculation plate in which the fluidic resistances having V-shape channels are defined, a nozzle plate, a descender plate, and a collar. The nozzle recirculation plate is positioned between the nozzle plate and the descender plate and the integrated recirculation manifold is positioned between the collar and the descender plate, The carbon body is in contact with the integrated recirculation manifold.

In general, in an aspect, a recirculation flow rate for recirculation flow paths for nozzles of ink jets of an inkjet assembly is selected and a maximum external pressure to be applied to the recirculation flow paths is selected. A refill resistor having fluidic resistances to provide a fluid flow rate from the refill resistor that is similar to a sum of nozzle recirculation flow rates for the nozzles is designed.

Implementations may include one or more of the following features. The nozzle recirculation flow paths for the nozzles are connected in parallel. A fluid flow path from the refill resistor is connected in parallel to the nozzle recirculation flow paths from the nozzles. The maximum external pressure is between 10-40 inwg.

In general, in an aspect, a portion of a fluid in a nozzle of an inkjet of an inkjet assembly flows from the nozzle through a recirculation path to a reservoir separate from the inkjet assembly.

Implementations may include one or more of the following features. The portion of the fluid flows at a rate that is 10% of a flow rate of the fluid that is ejected from the nozzle. A second portion of the fluid is directed through a refill resistor; and the second portion of the fluid that has flown through the refill resistor is directed out of the inkjet assembly. The second portion of the fluid is directed to the refill resistor upstream of where the portion of the fluid is directed through the recirculation path. A flow rate of the second portion of the fluid through the refill resistor is within ±50% of a sum of flow rates from the nozzles of the inkjet assembly. A combined flow rate of the second portion of the fluid through the refill resistor and the sum of flow rates from the nozzles of the inkjet assembly is 10 μcc/sec.

In general, in an aspect, non-linear channels are formed in a nozzle recirculation plate, one end of each of the channels opening into a nozzle, and another end of each of the channels is connected to a fluid path that extends out of nozzle recirculation plate.

Implementations may include one or more of the following features. A length of each of the non-linear channel is a first multiple of a manufacturing tolerance of the channel. A width of the non-linear channel is a second multiple of the manufacturing tolerance of the channel, and the first multiple is much greater than the second multiple.

In general, in an aspect, an apparatus includes a plate through which at least portions of ink jetting nozzles extend from one face of the plate to another face of the plate, and V-shaped ink recirculation paths formed in the plate, each path having one end opening into the portion of a corresponding ink jetting nozzle and a second end for coupling to an ink recirculation path external to the plate.

These and other features and aspects, and combinations of them, can be expressed as systems, components, apparatus, methods, means or steps for performing functions, methods of doing business, and in other ways.

Other features, aspects, implementations, and advantages will be apparent from the description and the claims.

DESCRIPTION

FIG. **1**A-**1**C show isometric views of a printhead assembly.

FIGS. **1**D-**1**H are views of a printhead assembly.

FIG. **2** is a schematic representation of fluidic connections within the printhead assembly.

FIGS. **3**A-**3**E are top, side, left end, right end, and bottom views of a collar.

FIGS. **4**A-**4**D are top, bottom, left and right sectional views of a manifold.

FIG. **4**E is a side view of a carbon body.

FIG. **4**F is a schematic view of an arrangement of parts within an inkjet array module.

FIGS. **5**A-**5**C are top, and large top, and further enlarged top views of a nozzle recirculation manifold.

FIGS. **6**A and **6**B are schematic perspective views of a nozzle plate.

FIG. **7** are perspective views of the descender plate, the nozzle recirculation plate and the nozzle plate.

FIGS. **8**A and **8**B are schematic perspective views of the ink flow through the printhead assembly.

As shown in FIG. **6**A, a nozzle plate **600** has nozzle openings **601**. The nozzle plate **600** has an exposed surface **603** that faces a printing medium **604**; each of the nozzle openings is at the exposed surface **603**, and ink droplets from each jet are ejected from the nozzle opening toward a substrate during printing.

As shown in FIG. **6**B, the nozzle opening for each jet lies at the end of a nozzle tube **607** in a nozzle plate **600**. At times when ink droplets are not being ejected from the nozzle opening, ink is held in the nozzle tube to prepare the nozzle for subsequent jetting of droplets. The ink in the nozzle tube then forms a meniscus **605** of ink **170** to define a liquid-air interface **606** within the nozzle tube **607** The meniscus **605** may have an outer rim **691** at the nozzle opening and a concave surface **693** caused by a negative pressure applied to the ink **170** upstream of the nozzle to keep it from leaking from the nozzle opening. (We often use the term nozzle interchangeably with the term nozzle tube.) The meniscus **605** extends over the diameter **608** of the nozzle opening **601** and is positioned within the nozzle tube **607** of the nozzle opening **601**, away from the exposed surface **603**. The ink, which can include pigments and solvents, may dry or undergo other changes in its characteristics at the nozzle opening **601** and within the nozzle tube, for example, when volatile solvents **609** evaporate from the ink through the liquid-air interface **606** of the meniscus **605**. Ink that is held in and flows through various parts of the inkjet array module is also subject to settling of pigments and to other changes in characteristics that can adversely impact the quality of the printing and the maintenance of the inkjet array module. To reduce these effects, ink can be recirculated continuously while the inkjet array module is in operation or in an idle state. For this purpose, recirculation can be carried out, for example, at a refill chamber **191** (FIGS. **1**E, **4**E and **8**A) of an inkjet array module **16**A (FIG. **1**E), upstream of individual pumping chambers **2201** (FIGS. **4**F and **8**A). Several inkjet array modules can be installed in a printhead assembly **10**.

The refill chamber **191** houses a larger volume of ink **170** compared to the ink contained in individual pumping chambers **2201**. Recirculating ink at the refill chamber **191** helps to prevent heavier pigments of inks **170** from settling there. Recirculating at the refill chamber **191** helps to ensure that ink having specific characteristics (for example, viscosity, temperature, amount of dissolved gases) is delivered to individual pumping chambers **2201** for jetting. In addition, a deaerator can be arranged upstream of the refill chamber to remove gases from the ink supplied to the refill chamber **191**. In that way, inks having very low dissolved gas content can be supplied to pumping chambers **2201** for jetting. Recirculating ink **170** at the refill chamber **191** also facilitates changing of inks because the refill chamber recirculation flow paths provide a fluid path for the ink **170** in the refill chamber **191** to be actively removed (using back pressure exerted from an external source **120**) from the printhead assembly **10** in order for new inks to be introduced to the printhead assembly **10**. In the absence of the recirculation fluid paths, a particular ink would need to be flushed from the nozzles **249** before new ink can be introduced to the printhead assembly **10** (assuming that the printhead assembly **10** is not disassembled between changes of ink). Recirculation of ink also helps with priming and recovery. An empty printhead containing air can be primed by introducing a jetting fluid into the printhead such that a meniscus of the jetting fluid is formed at one or more nozzles of the printhead. Priming generally refers to the preparation of a meniscus at the nozzle.

In addition to recirculating ink at the refill chamber, recirculating ink **170** that is being held in and upstream of the nozzle **249** from which ink droplets are to be ejected helps to ensure that fresh ink, of the same characteristics (e.g., viscosity, temperature, and solvent content) as the ink that is in the refill chamber **191** is held in the nozzle **249**, for example, during the time when ink is not actually being jetted. Recirculation helps to ensure that, for example, the first droplet jetted from the nozzle opening **250** after a period of no jetting is of the same quality, size, and characteristics as other droplets that are jetted before and after the period of no jetting. This allows for better jetting performance.

For example, inks that contain volatile solvents may be dried out within the nozzle **249** when the meniscus **605** of the ink **170** at the ink-air interface **606** loses the volatile solvents **609** at the interface to the atmosphere, in the absence of recirculation. Some inks may absorb air through the ink-air interface **606** at the meniscus **605** when the ink is exposed to air. This absorption may cause bubble formation within the printhead assembly **10** that can render the printhead inoperable when these bubbles are trapped in ink passages in the printhead assembly **10**.

To recirculate ink that is held in the nozzle tube at times when the inkjet is not ejecting droplets from the nozzle opening can be done by providing a recirculation path that opens at one end into the nozzle tube and leads at its other end to a recirculation supply of ink. We describe such nozzle recirculation paths below. Note that, as shown in FIG. **7**, the nozzle tube **607** includes not only the segment that lies within the nozzle plate but also a collinear segment within a nozzle recirculation plate **20**, and at least part of the nozzle recirculation path is provided in the nozzle recirculation plate, as described in more detail below.

Providing such recirculation paths from the nozzle tubes is not trivial due to space constraints in body in which the nozzles are formed. The inclusion of recirculation paths to closely spaced nozzles may also create cross talk between jets (explained in more detail below). Recirculation may also reduce efficiency of the jetting, because it draws some ink from the nozzle tube and reduces the ink pressure in the nozzle tube, which can reduce the amount of jetting fluid that is being ejected in a droplet from the nozzle opening onto the printing substrate. The recirculation flow also may perturb the meniscus pressure at the nozzle leading to a heightened sensitivity of the nozzle to the fluctuations in the recirculation pressure.

Ink flows at a nominal flow rate as it is ejected through each of the nozzle onto a substrate. Ink is held under a nominal negative pressure associated with a characteristic of a meniscus of the ink in the nozzle when ejection of ink from the nozzle is not occurring. Each flow path having a nozzle end at which it opens into one of the nozzles and another location spaced from the nozzle end that is to be subjected to a recirculation pressure lower than the nominal negative pressure so that ink is recirculated from the nozzle through the flow path at a recirculation flow rate. Each recirculation flow path has a fluidic resistance between the nozzle end and the other location such that a recirculation pressure at the nozzle end of the flow path that results from the recirculation pressure applied at the other location of the flow path is small enough so that any reduction in flow rate below the nominal flow rate when ink is being ejected is less than a threshold, or a change in the nominal negative pressure when ink is not being ejected is less than a threshold, or both.

In some inkjet heads, the ink **170** is split into two paths in a recirculation structure immediately upstream of the nozzle plate **21**. One of the paths conducts the ink to the nozzle plate **21**, from which ink is ejected. The other path provides a path for the ink to flow out of the printhead assembly **10** into an external ink reservoir **110**.

A recirculation flow rate for recirculation flow paths for nozzles of ink jets of an inkjet assembly is selected and a maximum external pressure to be applied to the recirculation flow paths is selected. A refill resistor having fluidic resistances to provide a fluid flow rate from the refill resistor that is similar to a sum of nozzle recirculation flow rates for the nozzles is designed. A portion of a fluid in a nozzle of an inkjet of an inkjet assembly flows from the nozzle through a recirculation path to a reservoir separate from the inkjet assembly.

In FIG. **1A**, an inkjet printhead assembly **10** has an ink inlet **11**, and an ink outlet **12**. The ink inlet **11** is connected to an external ink reservoir **110** through a tubing coupler **109** and piping **111** so that the ink reservoir **110** supplies ink **107** to the ink inlet **11** (in the direction indicated by arrow **103**). The external ink reservoir **110** is also connected to the ink outlet **12** through a tubing coupler **105** and piping **112** and receives returned ink from the ink outlet **12** (in the direction indicated by arrow **101**). The external ink reservoir **110** is connected to a vacuum source **120** through vacuum connections **121**. The vacuum source **120** can exert a vacuum pressure on the ink in the ink reservoir **110**.

The printhead assembly **10** includes a rigid housing **13** formed of two half-pieces **9** and **7**, which (when assembled) encapsulate components of the printhead assembly **10**. Examples of materials from which the two half-pieces of rigid housing **13** can be made include thermoplastics. The ink inlet **11** enters the housing **13** through a ring-shaped resilient support **156** that is captured in a round aperture **1001** formed on the upper wall of the housing **13** when the two half-pieces are mated.

Similarly, the ink outlet **12** leaves the housing **13** through a resilient ring support **155** that is captured in a round aperture **1004** formed in the upper wall of the housing **13** when the two half-pieces are mated. The bottom **1006** of the housing **13** has an inwardly projecting rim **1008** on both ends that mates with corresponding grooves **1010** on opposite ends of a collar **14**. The bottom surface **1012** of the collar **14** is joined using adhesives **1014** to an integrated recirculation manifold **15**. The integrated recirculation manifold **15** is a separate piece from the collar, and integrates the flow paths of two recirculation systems. Details of the recirculation systems are described below.

The integrated recirculation manifold **15** is affixed using adhesives, such as epoxies, to a laminated piece **23** that includes a stainless steel descender plate **17** and a stainless steel nozzle recirculation plate **20**. The bottom surface **1018** of the recirculation plate **20** is then joined adhesively to a nozzle plate **21**. The collar, the recirculation manifold, the descender plate, the recirculation plate, and the nozzle plate all have the same peripheral size and shape.

The collar **14**, the integrated recirculation manifold **15**, the descender plate **17**, the nozzle recirculation plate **20** and the nozzle plate **21** jointly form a nozzle plate assembly **221**. The collar and the integrated recirculation manifold **15** may be made of carbon, while the nozzle plate **21** may be an electroform plate of nickel.

The collar **14** includes two protrusions **140** and **141**. The protrusion **140** has two through-holes **142** and **143** through which two screws **130** and **131** can extend, while the protrusion **141** has a single through-hole **144** through which a screw **133** can extend. The screws **130**, **131** and **133** allow the printhead assembly **10** to be mounted, along with other printhead assemblies, on a print bar **1016**, or other supports. The housing **13** can be opened into two halves along a seam **150**. A multiple-contact electrical connector **157** at the top of the assembly can receive a mating connector of a signal cable to enable signals to be carried to and from actuation elements of the printhead assembly used to trigger jetting of ink from each inkjet, for example. Using the three mounting screws, the tubing couplings **105** and **109**, and the electrical connector **157**, the entire printhead assembly can be easily removed as a stand-alone assembly from the print bar **1016**, for maintenance, storage, or replacement.

As shown in FIG. **1B**, within the printhead assembly four inkjet array modules **16A-16**D are arranged in two pairs, each pair mounted in corresponding long rectangular slots **161** and **162** in the collar **14**. Slots **161** and **162** are separated by a wall **163** that extends along the length of the collar **14**. Each array module includes two flexible circuits **166** that are connected to circuitries mounted on a circuit board **158** supported within the housing **13**. A heater wire **165** is optionally included in some printhead assembly **10**. The heater wire **165** can be used to heat up the ink **107** that is supplied into each of the inkjet array modules **16A-16**D.

The ink inlet **11** is connected, as shown in FIG. **1C**, to the collar **14** at a throughhole **200** in the wall **163** by way of a piping **1100** and a coupler **1105**. The ink outlet **12** is connected to the collar **14** at a throughhole **122** in the wall

163 of the collar **14** through a coupler **1110** and a piping **1115**. A second return **1421** from the recirculation manifold is formed as a horizontal channel in the collar **14**. The four pairs of flexible circuits **166** are connected to electronic circuitries **171** arranged on the board **158**.

FIG. **1**D shows a cross-sectional end view of the printhead assembly **10**. Integrated circuits **180** are mounted on each flex circuit **166**. Aluminum clamps **184** span the length of each of the inkjet array modules **16**A-**16**D (into and out of the plane of the drawing). There is a screw **185** at each end of the aluminum clamp **184**, the screw having a screw head **186** positioned above the clamp **184**. Each of the array modules **16**A-**16**D includes a carbon body **190**, in which a refill chamber **191** is defined. All four refill chambers **191** for the array modules **16**A-**16**D are fluidically connected. The carbon body **190** is sandwiched between stiffener plates **210**, **211** and cavity plates **212** and **213** (shown more clearly in FIGS. **1**F and **4**F) An enlarged view of the lower left portion of the printhead assembly (marked with a rectangle) is shown in FIG. **1**E.

FIG. **1**E shows two array modules **16**A and **16**B. A descender **192** is defined in the carbon body **190** for each nozzle of the module. The descender **192** includes a 90 degree bend joining an orifice **1641** to an orifice **1642** at a bottom edge **1640** of the carbon body **190**. The descender **192** extends through the integrated recirculation manifold **15** as a descender **194**. The integrated recirculation manifold has an upper surface **1510** and a lower surface **1515**. A nozzle recirculation return manifold **193** and a refill recirculation resistor **42** is defined in the upper surface **1510** of the integrated recirculation manifold **15** (FIG. **4**A). A total of eight recirculation return manifolds **19** are defined in the lower surface **1515**, of which five are shown in FIG. **1**E. An enlarged view of the lower middle portion of FIG. **1**E is shown in FIG. **1**F.

The descender **194** defined in the integrated recirculation manifold **15** connects an end of descender **192** to a descender **220** defined in descender plate **17**. An enlarged view of the lower left portion of FIG. **1**F is shown in FIG. **1**G.

FIG. **1**G shows a bottom up view (viewed from the nozzle plate **21**) of a portion of the nozzle plate assembly **221**. The nozzle plate assembly includes the collar **14**, the integrated recirculation manifold **15**, the descender plate **17**, the nozzle recirculation plate **20** and the nozzle plate **21**. The nozzle plate **21** contains a number of nozzle openings **250**. Each nozzle opening **250** in the nozzle plate **21** is smaller in diameter than any section above it. The top portions of the figure shows the recirculation return manifold **19** defined in the lower surface **1515** of the integrated recirculation manifold **15**. Below the manifold **15** is the descender plate **17** in which a number of descenders **220** and ascenders **230** are defined. A void **240**, also known as a "glue sucker", serves as an adhesive control feature by holding glue squeezed out between the recirculation manifold **15** and the descender plate **17** during assembly. The descenders **220** are aligned with a port **22** in the nozzle recirculation plate **20**. The descender plate **17** is adhesively bonded to the nozzle recirculation plate **20** to form the laminate piece **23**. The port **22** in the nozzle recirculation plate **20** is connected via a V-shaped nozzle recirculation resistor or channel **24** to a port **232** which is aligned with the ascender **230** in the descender plate **17** to the recirculation return manifold **19**. There are equal numbers of descenders **220** and ascenders **230** and the total number of descenders **220** matches the total number of nozzle openings **250**. In other words, each nozzle opening **250** has its own dedicated nozzle recirculation resistor **24**. The nozzle recirculation resistor **24** is, for example, a fluidic channel. Elements **231** are cross sections of other V-shaped nozzle recirculation resistors **24** that belong to other nozzles **250** arranged into and out of the plane of the drawing in FIG. **1**G. The ink that is delivered to the recirculation return manifold **19** exits the printhead assembly **10** through the ink outlet **12**.

FIG. **1**H shows a similar view of the nozzle plate assembly **221**, but without the nozzle plate **21**. Each V-shaped nozzle recirculation resistor **24** is connected to a respective nozzle opening **250** via the port **22**, while the other end of the resistor **24** is connected to the port **23** which directs ink to the recirculation return manifold **19** through the ascender **230** in the descender plate **17**.

The ink **170** enters the printhead assembly **10** through the ink inlet **11**, flows through the throughhole **200** in the collar **14**, into slot **45** of the integrated recirculation manifold **15**, through throughholes **44** (FIG. **4**A), and into a refill chamber **191** (FIG. **4**E) before the ink is directed to individual pumping chambers **2201** associated with a respective nozzle opening **250**. Ink from the pumping chambers may be jetted from a specific nozzle opening **250**, or the ink may not be jetted from the nozzle opening **250** and is instead directed through the nozzle recirculation resistor **24** for that specific nozzle opening **250** and return to the recirculation return manifold **19** before it is combined with the ink exiting the refill recirculation resistor **42** associated with the refill chamber **191** and directed out of the printhead assembly **10** through the ink outlet **12**.

FIG. **2** illustrates fluidic connections within the printhead assembly **10**. Ink from reservoir **110** enters the ink inlet **11** and is relayed by an ink supply (that includes piping **1100** and the coupler **1105**) to the refill chamber **191**. One end of a refill recirculation resistor **42** is connected in series to the refill chamber **191** while the other end of the refill recirculation resistor **42** is connected to a fluidic path that leads to the ink outlet **12**. The refill chamber **191** supplies ink **170**, in parallel, to all the pumping chambers **2201** of the printhead assembly **10**. In some printhead assemblies, there may be 1024 pumping chambers. The total number of pumping chambers in each printhead assembly equals the total number of nozzle openings in the printhead assembly. The fluid flow path between each pumping chamber **2201** and its corresponding nozzle opening **250** is independent of the other fluid flow paths connecting other pumping chambers to their respective nozzles. In other words, there are as many independent, parallel fluidic flow paths from the pumping chambers **2201** as nozzles. Between each pumping chamber **2201** and each nozzle opening **250** is an inlet to a nozzle recirculation resistor **24**. As a result, each fluidic path from the refill chamber **191** to the nozzle opening **250** has a specific nozzle recirculation resistor **24**. All the nozzle recirculation resistors are connected in series to a recirculation return manifold **19**. The ink leaving recirculation return manifold **19** merges with the ink returning from the refill chamber **191** before all the return ink is directed out of the printhead assembly **10** through ink outlet **12**.

FIGS. **3**A-**3**D show details of the collar **14**. The throughhole **200** in the wall **163** receives ink flowing down the piping **1100** from the ink inlet **11** through the coupler **1105** to the throughhole **200**. The throughhole **200** does not extend straight through the collar **14**. Instead, the opening of the throughhole **200** on a top surface **1011** of the collar **14** is offset from the opening of throughhole **200** on the bottom surface **1012** of the collar **14** as shown in the cross section illustrated in FIG. **3**D. Similarly, the top and bottom surface openings of the throughhole **122** which receives ink from the recirculation return manifold **19** and a refill recirculation resistor **42** is also offset, as shown in FIG. **3**C. The ink entering the throughhole **122** flows through the coupler **1110** into the piping **1115** before leaving the printhead assembly **10** through ink outlet **12**. Grooves **1010** on either side of the collar **14** (shown in FIG. **3**B), are used to engage the projecting rim **1008** on the housing **13**. A top channel **1020** allows a cartridge heater (typically the shape of a long round rod) to be inserted. The cartridge heater can be used to heat up the ink **107** contained within each of the array modules **16**A-**16**D. A lower channel **1030** provides a space through which a thermistor used for temperature sensing can be inserted. The slots **161** and **162** in the collar **14** can each accommodate two inkjet array modules (**16**A-**16**D).

The flow path of ink that enters the collar **14** through throughhole **200** is as follows: upon leaving the bottom face **1012** of the collar **14**, the ink is directed into a slot **45** in the integrated recirculation manifold **15**. The slot **45** extends through the entire thickness **1525** (shown FIG. **4**C) of the integrated recirculation manifold **15**. On the bottom surface **1515** of the integrated recirculation manifold **15** are four additional channels **1521**-**1524** branching off from slot **45**. Each of the channels **1521**-**1524** is used by one of the inkjet array modules **16**A-**16**D. Ink that is directed into the slot **45** is evenly distributed into each of these branches and delivered to inkjet array modules **16**A-**16**D. At the end of each of these branches is a throughhole **44** that opens vertically to the top surface **1510** of the recirculation manifold **15**. The ink flowing through channels **1521**-**1524** leaves the top surface **1510** of the integrated recirculation manifold **15** through the throughholes **44**.

As shown in FIGS. **1**B and **1**D, inkjet array module **16**A-D are mounted within slots **161** and **162**. Each array module includes a carbon body **190** (shown in FIG. **4**E) in which a refill chamber **191** is defined. A bottom edge **1640** of the carbon body **190** rests on the integrated recirculation manifold **15** when the array modules **16**A-D are assembled in the slots **161** and **162** of the collar **14**. The hashed portions of FIG. **4**E expose the subsurface features of the carbon body **190**. When the carbon body **190** of the inkjet array module is assembled within either slot **161** or **162** in the collar **14**, and contacts the top surface **1510** of the integrated recirculation manifold **15**, the opening of channel **1530** on the edge **1640** of the carbon body **190** lines up with the throughhole **44** of the integrated recirculation manifold **15**. In this way, the ink that leaves the top surface **1510** of the recirculation manifold **15** enters the channel **1530** in the carbon body **190** and is directed upwards into the ink refill chamber **191**.

Once the ink enters refill chamber **191**, three possible flow paths are possible. Some ink follows a first flow path and flows out of the plane of the drawing in FIG. **4**E and into the cavity plate **212** which contains pumping chambers **2201**. Some ink follows a second flow path and flows into the plane of the drawing and into the cavity plate **213**. Both of these flow paths deliver ink to either the nozzle opening **250** or the nozzle recirculation resistor **24**.

The third possible flow path delivers ink to the refill recirculation resistor **42**. This part of the ink leaves the refill chamber **191** through a channel **1540**. The channel **1540** has an opening at the edge **1640** of the carbon body **190** and is aligned to a throughhole **414** in the top surface **1510** of the recirculation manifold **15**. The throughhole **414** is connected on the bottom surface **1515** of the integrated recirculation manifold **15** to one of the four branches **1541**-**1544** defined on the bottom surface **1515**. Each of the four throughholes **414** is connected to a respective one of the four branches **1541**-**1544**. Each array module (**16**A-**16**D), when mounted within slots **161** or **162**, uses one of the four branches for returning ink from the refill chamber to the reservoir. All four branches **1541**-**1544** are connected at a slot **43** which forms part of a refill recirculation manifold **420**. The slot **43** extends through the entire thickness **1525** of the recirculation manifold **15** and is connected to one end of the refill recirculation resistor **42**. The other end of the refill recirculation resistor **42** is connected to the throughhole **412** which is aligned to the throughhole **122** in the collar **14**.

FIG. **4**F shows a cross sectional view of the carbon body **190**, stiffener plates **210** and **211**, cavity plates **212** and **213** in which pumping chambers **2201** are defined, membranes **1740** and **1741**, and piezoelectric plates **1750** and **1751** having piezoelectric elements positioned over each of the pumping chambers **2201**. The piezoelectric elements apply forces on the ink in the pumping chambers **2201** and ink flows through a side opening in the cavity plates (more details about the flow paths are described in [0295001], which is incorporated by reference in its entirety) and return to the carbon body **190**, entering through a respective orifice **1641** corresponding to a particular pumping chamber. The orifice **1641** opens to descender **192** which includes a 90 degree bend channel (shown in FIGS. **1**E and **1**F and **4**F), with an exit orifice **1642** that is defined in the edge **1640** of the carbon body **190**. The exit orifice **1642** is set on the integrated recirculation manifold **15** to line up with the descender **194**. There are two rows of orifices **1642** in each inkjet array module, and these rows of orifices line up with the two corresponding rows of descenders **430** defined in the integrated recirculation manifold **15**.

Ink that has been pressurized in the pumping chamber **2201** now enters the top surface **1510** of the integrated recirculation manifold **15** through descenders **430** which extend through to the lower surface **1515** of the integrated recirculation manifold **15**. The ink then flows down descenders **220** in the descender plate **17** and enters a port **22** in the nozzle recirculation plate **20**. At the port **22**, ink can either be directed down towards the nozzle plate **21** or it can be drawn by the vacuum applied to the integrated recirculation manifold **15** and the nozzle recirculation plate **20** and flow in a V-shaped fluidic channel **24**. The ink that flows towards the nozzle plate **21** leaves the printhead assembly **10** and is ejected from nozzle opening **250** onto a printing medium. The ink that enters V-shaped fluidic channel **24** flows into the port **23** which opens upwards to ascender **230** in the descender plate **17**. FIG. **7** illustrates these two possible flow paths in greater detail. The ink **170** leaving the descender **220** in descender plate **17** of the laminate piece **23** enters the port **22** of the nozzle recirculation plate **20**. A portion **171** of the ink **170** continues down the nozzle tube **249** of the nozzle plate **21** and forms a meniscus **605** within the nozzle tube **249**, a distance away from an exposed side of the nozzle opening **251** in the nozzle plate **21**. A portion **172** of the ink **170** is conducted through the V-shaped nozzle recirculation resistor or channel **24** defined within the nozzle recirculation plate **20**. The recirculation channels **24** are open on both the top and bottom faces of the nozzle recirculation plate **20**. In other words, the height of the recirculation channels **24** is the same as the thickness of the nozzle recirculation plate **21**. The descender plate **17** bounds the upper part of the channels **24** while the nozzle plate **21** bounds the lower part of the recirculation channels **24**. The portion **172** of the ink reaches the port **23** and is conducted upwards to the ascender **230** in the descender plate **17** before entering the recirculation return manifold **19** (FIG. **4**B) on its flow path out of the printhead assembly **10**. Solvents in the ink can be resupplied to the ink at the nozzle while dissolved air contained in the ink at the nozzle can be reduced by diffusion back into the fresh ink. The ink does not have to be physically replaced at the nozzle to benefit from recirculation of ink just behind the nozzle.

The diameter **2405** of port **23** is smaller than the diameter **2404** of port **22**. The recirculation return has a lower flow rate so the diameter **2405** of the port **23** can be smaller. The diameter of port **22** matches the other part openings (e.g., the descender **220** in the descender plate **17**) in the stack that makes up the overall descender structure. The ratio of the amount of ink that flows into the fluidic channel **24** to the amount of ink that flows into the nozzle opening **250** is determined by the back pressure that is applied to the nozzle recirculation plate **20**. In other words, there is a pressure differential between the jetting passage (from the port **22** to the nozzle opening **250**) and the recirculation circuit (from the port **22** to the fluidic channels **24**). The meniscus pressure is typically 1 inch of water (inwg) and the recirculation pressure is typically 10 to 30 inwg, giving a typical ratio of between 10 to 30:1. Generally, the ratio may be greater than 10. The presence of the recirculation flow introduced by the recirculation circuit can be viewed as parasitic losses in the overall jetting of the printhead assembly. Manifestations of such parasitic losses can include lower velocities of ink that is delivered to the nozzle opening **250**, and reductions in ink drop mass delivered to the nozzle opening (due to the diversion of some ink into the fluidic channels **24** at port **22**). The actual magnitude of the drop mass and velocity reduction are influenced by the variation in the pressure differential between the jetting fluid passage and the recirculation circuit. In addition, the presence of recirculation circuits can also increase cross-talks between jets. While each jet has its own recirculation resistor, and the recirculation fluidic flow runs in parallel, and not in series between different jets, energy can still travel down a recirculation resistor to the recirculation manifold, and then from the recirculation manifold back down a different recirculation resistor to a different jet. As a result, there still exists a fluidic path between different jets that would not have existed without the recirculation structures. The loss of efficiency and crosstalk can be minimized by reducing the amount of acoustic energy that can enter the recirculation system (manifold).

Reducing the recirculation flow and the dimensions of the fluidic channels in the recirculation circuits lessen the demands placed on the control of pressure differentials and also reduces the effect of cross talk between jets.

Due to limitations of manufacturing precision (expressed, for example, as an etching uncertainty of ±x mm), smaller recirculation passages having fine fluidic channels experience greater variations in fluidic resistance and the resulting recirculation flow. For example, for a fluidic channel having a width of 10 microns, an etching uncertainty or tolerance of ±1 micron will result in a 10% variation in its width. Compared with a wider fluidic channel having a width of 1000 micron, the etching uncertainty of ±1 micron will only result in a 0.1% variation in its width. In addition, the adhesive bonding of the nozzle recirculation plate **20** with the descender plate **17** to form the laminate piece **23** may cause the inadvertent deposition of adhesive materials within the thin recirculation channels, blocking the ink's fluidic access through those channels.

In general, non-linear channels are formed in a nozzle recirculation plate, one end of each of the channels opening into a nozzle, and another end of each of the channels is connected to a fluid path that extends out of nozzle recirculation plate. The apparatus includes a plate through which at least portions of ink jetting nozzles extend from one face of the plate to another face of the plate, and V-shaped ink recirculation paths formed in the plate, each path having one end opening into the portion of a corresponding ink jetting nozzle and a second end for coupling to an ink recirculation path external to the plate.

When we use the term fluidic resistance, we broadly include, for example, forces that act on a fluid as it flows through a channel. In some cases, the fluidic resistance can be represented by a parameter that can be a function of a length and a cross-sectional area of the channel. In some examples, fluidic resistance increases as the length of the channel increases, and fluidic resistance decreases as the cross-sectional area of a channel increases.

To minimize the sensitivity of the nozzle recirculation manifold towards such manufacturing uncertainties, the length of the fluidic channels can be maximized (for example, to 100 times the manufacturing tolerance). As described above, fluidic resistance of a channel is a function of the cross-sectional area and length of the channel. In particular, fluidic resistance is directly proportional to the length of the channel and inversely proportional to the cross-sectional area of the channel. By increasing the length of the fluidic channels to a large ratio of the manufacturing tolerance, (and thus increasing the fluidic resistance of the channel), the width (of the cross-sectional area) can then selected to be as large as possible (which reduces the fluidic resistance of the channel), for example, to five times the manufacturing tolerance, such that the product of the length of the cross sectional area yields the desired fluidic resistance. Typically, the height of a fluidic channel is determined by the stock thickness of the stainless steel plate from which the nozzle recirculation manifold plate is fabricated. In general, the thickness of the stainless steel plate is manufactured to a tighter tolerance, for example, of ±8 microns, compared to the etching uncertainty or tolerance of ±15 microns.

The width **2401** of the V-shaped channel **24** can be 75 microns. This dimension is determined by the material thickness. Given how the parts are fabricated, the material thickness is typically not smaller than 51 microns. As shown in FIG. **5**C, while ports **22** and **23** in a particular row **52** line up vertically, there is an offset **2402** between the position of port **22** in one row from the position of port **22** in an adjacent row. The two rows of orifices are offset from one another along the length of the carbon body by a distance that is one half of the spacing between the orifices. The orientation of the V-shape channels also alternates between rows. In one row **53**, the pointed end **2410** of the V-shape channels are to the right of the open end **2412** of the V-shape channels, whereas in the adjacent row **52**, the pointed end **2410** of the V-shape channel is to the left of the open end **2412** of the V-shape channels. This arrangement helps to conserve space on the nozzle recirculation manifold plate. The angle **2401** of the V-shaped bend of the channel **24** is typically between 40°-60°, for example, 50°. In general, the larger the angle **2401**, the longer the fluidic channel **24**. The land space between the ports determines the angle, a smaller amount of land space would necessitate a larger angle. For an angle increase of 5°, the length of the fluidic channel is decreased by 0.2 mm. The radius of curvature **2402** of the channel is between 0.10 mm to 0.20 mm, for example, 0.12 mm. Too small a radius of curvature (or too sharp a corner) may cause reflection of the fluid within the fluidic channels, leading to a fluidic pressure reflection. The V-shape formation of the channels helps to increase the land to channel area ratio, optimize the limited area available on the nozzle recirculation plate **20** for the placement of fluidic channels. Reducing the land to channel area ratio reduces the amount of adhesives (e.g. epoxies), for a given amount of fluidic resistance, that are applied on the nozzle recirculation plate **20** to bond with the descender plate **17** to form a laminate piece **23**. The pitch of the fluidic channel is identical to the spacing between ports **22** (and thus, the nozzle openings **250**). The ink that enters the ascender **230** flows into the recirculation return manifolds **19**, defined in the bottom surface **1515** of the integrated recirculation manifold **15**, that services that particular row of ascenders. In some cases, there are eight rows of nozzle openings **250** in the printhead assembly that accommodates four inkjet array module (each inkjet array module utilizes two rows of nozzle openings). All eight recirculation return manifolds **19** are connected by perpendicular channels **410** and **411**. Perpendicular channels **410** and **411** each has a respective throughhole **412** and **413** that opens to the top surface **1510** of the integrated recirculation manifold **15**. Throughholes **412** and **413** bound the two ends of nozzle recirculation return manifold **193** and the throughhole **412** is aligned with the throughhole **122** in the collar **14**. As described earlier, the ink entering the throughhole **122** flows through coupling **1110** into the piping **1115** before leaving the printhead assembly **10** through the ink outlet **12**. Throughhole **412** also reunites ink from the refill recirculation manifold to the ink from the nozzle recirculation return manifold.

The use of two recirculation circuits, a nozzle recirculation circuit and an ink refill chamber recirculation circuit, connected in parallel and driven by back pressure (i.e., a nominal negative pressure) from a single external vacuum source **120**, means that the recirculation of ink in the larger ink refill chamber needs to be controlled carefully to prevent undesirable pressure fluctuations in the meniscus pressure of the ink droplet supported at the nozzle opening **250** of the nozzle plate **21** that are caused by the ink refill chamber recirculation circuit. In general, ink is ejected from the inkjet assembly at a nominal flow rate. The recirculation pressure experienced at the nozzle end of the recirculation flow path is small enough so that any reduction in flow rate below the nominal flow rate when ink is being ejected is less than a threshold, or a change in the nominal negative pressure when ink is not being ejected is less than a threshold, or both. In general, the pressures required for nozzle recirculation are 5 to 10 times the pressure required for the ink refill chamber recirculation, in the absence of any additional fluidic resistance in the refill chamber recirculation. A nozzle recirculation rate and the required pressure are first selected, before the refill resistor is designed to provide a flow similar to the sum of the nozzle recirculation flows from all the jets. When the refill recirculation resistor **42** is introduced between the return ink from the ink refill chamber **191** and the ink outlet **12**, the resistor **42** can be designed so that a modest flow can be maintained at a pressure that is easily generated and controlled to within ±20% by the external vacuum source **120**. The combined recirculation flow (from the refill chamber and from all the nozzle recirculation flow paths) is about 10% of jetting flow or 10 μcc/sec. Keeping the recirculation flow rates to approximately 10% of the max jetting flow ensures that the effect of recirculation on the meniscus pressure is minimal. Recirculation flow rates in a range of x % to y % would also be useful. Thus, by inserting the appropriate fluidic resistance in the ink refill chamber recirculation circuit, the pressure required to pull the fluids in the two recirculation circuits can be equalized. In other words, by ensuring that the fluidic resistance in each of the recirculation circuits is about equal, or within 50% of each other, a single vacuum source can apply a large pressure that pulls approximately equally on both the nozzle recirculation circuit and the ink refill chamber recirculation circuit. The recirculation passages can have a high resistance of, for example, 5 $(\text{dyne/cm}^2)/(\text{cm}^3/\text{sec})$). For example, a vacuum of between 10-40 inches of water (inwg), also known as the recirculation pressure, can be pulled by the vacuum source **120** without influencing a meniscus pressure of the ink at the nozzle opening **250**. Such recirculation pressures are relatively easy (inexpensive) to generate and the high resistance makes the flow rate relatively insensitive to pressure fluctuations, making precision control unnecessary. The sum of all the nozzle recirculation flows is about equal to the refill recirculation flow. In other words, the refill resistance is approximately equal to the equivalent parallel resistance of all the nozzle resistances.

FIG. **8**A shows a schematic illustration summarizing the various flow paths of the ink **170** within the printhead assembly **10**. Ink **170** enters the printhead assembly **10** through the ink inlet **11** and is channeled to throughhole **200** in the collar **14**. The throughhole **200** opens to a slot **45** in the integrated recirculation manifold **15**. The slot **45** opens to four channels **1521-1524** (only **1521** is shown in FIG. **8**A) defined on the lower surface **1515** of the integrated recirculation manifold **15** (see details in FIGS. **4**A-**4**D). Each of the channels **1521-1524** terminates with a throughhole **44** that opens vertically to the top surface **1510** of the recirculation manifold **15**. Throughhole **44** is aligned with an opening **1530** in the carbon body **190** in an inkjet array module **16**A. The printhead assembly **10** can accommodate four injet array modules **16**A-**16**D (only parts of injet array module **16**A are shown in FIG. **8**A). The opening **1530** leads to ink refill chamber **191**. The ink **170** can be conducted out of the refill chamber **191** through the opening **1540**. The opening **1540** is aligned with throughhole **414** which opens to the channel **1541** defined on the lower surface **1515** of the integrated recirculation manifold **15**. The channel **1543** leads to a slot **43** which is connected to the refill recirculation resistor **42**, defined on the top surface **1510** of the manifold **15** (shown in more detail in FIG. **8**B). The refill recirculation resistor **42** terminates at the throughhole **412** which is aligned with the throughhole **122** in the collar **14**. The ink **170** then flows to the ink outlet **12** via the throughhole **122** and exits the printhead assembly **10**. The ink path of the ink **170** through the opening **1540**, into the channel **154**, the slot **43** and the refill recirculation resistor **42** is the flow path associated with the recirculation of the refill chamber.

At the ink refill chamber **191**, some ink **170** flows laterally (into and out of the plane of the drawing in FIG. **8**A, only ink flowing out of the plane of the drawing is shown in FIG. **8**A) through a similar passage defined in the upper portion of the stiffener plate **211** through to the cavity plate **213** having individual pumping chambers **2201**. When ink is jetted by piezoelectric elements associated with the pumping chambers **2201** (not shown), the ink **170** is forced out of the lower portion of the pumping chamber and enter orifices **340** defined in the stiffener plate **211** before entering the carbon body **190** through orifices **1641** (see FIG. **4**E for more details). The ink **170** negotiates the 90 degrees bend in the descender **192** in the carbon body **190** before entering the descender **194** in the integrated recirculation manifold **15** (FIG. **1**E). The ink **170** then passes through the descender **220** in the descender plate **17** and reaches port **22** in the nozzle recirculation plate **20**. Here, some ink **170** is conducted to nozzle opening **250** in the nozzle plate **21** while some ink passes through the V-shaped channel **24** to port **23** before the ink is conducted up to the ascender **230** in the nozzle plate **17** which is aligned with the recirculation return manifold **19** defined in the lower surface **1515** of the integrated recirculation manifold **15** (see FIG. **4**B). The ink **170** is then conducted by channels **411** and **193** to the throughhole **412** before it is expelled from the printhead assembly **10** through the ink outlet **12**. The low flow-high resistance recirculation system described above is implemented by taking advantage of the laminate structure common to the nozzle stack (nozzle plate **21**, the collar **14**, the descender plate **17**) of the inkjet array modules **16**A-D. The additional layer (i.e. nozzle recirculation plate **20**) is inserted between the nozzle plate **21** and the rest of the array module **16**A-D that contains the recirculation passages (one for each jet) and provides ports to a recirculation manifold.

Other implementations are also within the following claims.

What is claimed is:

1. A printhead comprising:

a plurality of nozzles defined in a body of the printhead, and

a nozzle recirculation flow path in fluid communication with one of the plurality of nozzles, the nozzle recirculation flow path defined in the body;

wherein, during use of the printhead, a portion of an ink that is not ejected from the nozzle is recirculated through the nozzle recirculation flow path.

2. An apparatus, comprising:

the printhead of claim **1**;

a reservoir separate from the printhead;

wherein the nozzle recirculation flow path is in fluid communication with the reservoir so that, during use of the apparatus, the portion of the ink in the nozzle not ejected from the nozzle flows from the nozzle through the nozzle recirculation flow path to the reservoir.

3. The printhead of claim **2**, wherein the printhead is configured so that, during use of the printhead, the portion of the ink flows in the nozzle recirculation flow path at a rate that is at least 10% of flow rate of the ink when it is ejected from the nozzle.

4. The printhead of claim **2**, wherein, during use of the printhead, ink flows at a flow rate as it is ejected from the nozzle, or ink is held under a negative pressure associated with a characteristic of a meniscus of the ink in the nozzle when ejection of ink from the nozzle is not occurring.

5. The printhead of claim **4**, wherein the nozzle recirculation flow path has a nozzle end at which it opens into the nozzle and a second location spaced from the nozzle end which, during use of the printhead, is subjected to a recirculation pressure lower than the negative pressure so that ink is recirculated from the nozzle through the nozzle recirculation flow path.

6. The printhead of claim **5**, wherein the nozzle recirculation flow path has a fluidic resistance between the nozzle end and the second location such that, during use of the printhead, a recirculation pressure at the nozzle end of the nozzle recirculation flow path that results from the recirculation pressure applied at the second location of the nozzle recirculation flow path is small enough that any reduction in flow rate below the flow rate when ink is being ejected is less than a threshold.

7. The printhead of claim **6**, wherein the fluidic resistance is defined in a nozzle recirculation layer of the body.

8. The printhead of claim **7**, wherein a V-shape channel of the nozzle recirculation layer defines the fluidic resistance.

9. The printhead of claim **8**, wherein a length of the V-shape channel is substantially greater than a width of the V-shape channel.

10. The printhead of claim **8**, wherein a radius of curvature at a bend in the V-shape channel is large enough to prevent fluidic reflections at the bend.

11. The printhead of claim **2**, further comprising a refill chamber and a second recirculation flow path that extends from the refill chamber.

12. The printhead of claim **11**, wherein the refill chamber is defined in the body.

13. The printhead of claim **11**, wherein the second recirculation flow path directs ink out of the printhead.

14. The printhead of claim **11**, further comprising an integrated recirculation manifold.

15. The printhead of claim **14**, wherein the integrated recirculation manifold is in fluid communication with the nozzle recirculation flow path and the second recirculation flow path.

16. The printhead of claim **15**, wherein the nozzle recirculation flow path and the second recirculation flow path are fluidically connected in parallel.

17. The printhead of claim **1**, wherein the plurality of nozzles is defined in a nozzle layer in the body of the printhead.

18. The printhead of claim **17**, wherein the nozzle recirculation flow path is defined in a nozzle recirculation layer that is in contact with and adjacent the nozzle layer.

* * * * *